MASTER'S THESIS

Cubesat Ground Station Implementation and Demonstration

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CUBESAT GROUND STATION IMPLEMENTATION AND DEMONSTRATION

SCHOOL OF ENGINEERING
MSc in ASTRONAUTICS AND SPACE ENGINEERING

INDIVIDUAL RESEARCH PROJECT REPORT
Academic Year: 2011 - 2012

Supervisor: Dr. Jenny Kingston
June 2012

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ABSTRACT

This project aims to develop a Cubesat Ground Station by utilizing amateur radio technology and COTS devices. Pursuing the work done by previous students, the system was finalised and then constructed. In addition, a further objective of this project is to design antenna mast support with tilting function for easy installation and maintenance.

Mast support design was carried out with the help of Catia V5 R17. As the structure will be bolted on the steel grid floor on the roof of B52A, it was suggested to be stronger as it will be on the roof and last for 10 years. With suggestions from amateur radio professional and mechanical technician, the support structure was designed to use two channels and then bolt to the base plate. Antenna mast was made of 3” and 2” galvanised steel tubes. To enable the pivoting function, a specially designed aluminium block is used to hold the mast and pivot around the pin joint.

Remote control of the Ground Station was enabled by remote controlling of the control computer. Splashtop desktop control software was selected for its fast control performance. However, to fully control the ground station, the power of each device has to be controllable, and also for the newly delivered polarisation switches. A Webserver controller was built by the inspiration of the IP Switch which was planned to use. It consists of an open source microcontroller Aruduino and its Ethernet Shield. Simple control interface was written in html code and embedded in the webserver. It controls the polarisation switches and power switch of each device, and also the radio on/off with a servo mechanism. Remote power on of the control computer was enabled by configuring its BIOS. Finally, the ground station is fully controllable.

Keywords:

Amateur Radio, Mast Design, Catia, Remote Control, Webserver Controller

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Rene Schimdt: Inventor of ERC-3D

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LIST OF ABBREVIATIONS

AFSK	Audio FSK
AGWPE	AGW Packet Engine
AM	Amplitude Modulation
AOCS	Altitude and Orbital Control Subsystem
AOS	Acquisition Of Signal
APRS	Automatic Position Reporting System
BER	Bit Error Rate
CAT	Computer Aided Transceiver
CI-V	Communication Interface-V
COTS	Commercial Off The Shelf
CW	Continuous Wave
DDE	Dynamic Data Exchange
DHCP	Dynamic Host Configuration Protocol
EMC	Electromagnetic Compatibility
EPS	Electrical Power Subsystem
FM	Frequency Modulation
FSK	Frequency Shift Keying
GEI	Geocentric Equatorial Inertial
GS	Ground Station
GSA	Generative Structural Analysis
HRD	Ham Radio Deluxe

HT	Hyper Terminal
ITU	International Telecommunication Union
KISS	Keep It Simple Stupid
LEO	Low Earth Orbit
LHCP	Left Hand Circular Polarisation
LOS	Loss Of Signal
LSB	Lower Side Band
MCR	Morse Code Reader
MSA	Mechanical Structures and Analysis
OBDH	On-Board Data Handling Subsystem
P-POD	Poly Pico-satellite Orbital Depolyer
PSK	Phase Shift Keying
RF	Radio Frequency
RHCP	Right Hand Circular Polarisation
SNR	Signal to Noise Ratio
SPL	Single Pico-Satellite Orbital Deployer
SSB	Single Side Band
TLE	Two Line Elements
TNC	Terminal Node Controller
T-POD	Tokyo Pico-Satellite Launcher
TT&C	Telemetry Tracking and Command Subsystem
USB	Upper Side Band

VSWR	Voltage Standing Wave Ratio
X-POD	eXperimental Push Out Deployer

Disclaimer

The author assumes no liability for any damage to equipment, loss of monies or injury sustained whilst executing work derived from the findings or recommendations of this work. The selection of appropriate equipment, installation and operating procedures, as well as time and economic cost budgeting is the responsibility of the authority executing such actions.

The author recognises that, whilst every effort has been made to ensure that the findings of this work are accurate, precise and robust, it has not been possible to consider every conceivable scenario in which they may be implemented and their subsequent effects.

1 PROJECT INTRODUCTION

This thesis report describes the work done for the Cubesat Ground Station project in Cranfield University, as part of the thesis project of MSc degree in Astronautics and Space Engineering. Continuing the previous projects (Long 2008; Kawak 2010, Soyer 2011), the finalization of the system design, all the tests and system construction procedures will be depicted in this report.

1.1 Background

The Space Research Centre of Cranfield University has been developing its first Cubesat named Cransat. This project is student involved for the purpose of education. Several studies have been carried out related to different segments of the main project:

- Structure analysis and optimization (Pauline 2010)
- Payload application (Dixon, A.P 2008)
- Attitude determination and control (Winter M. 2010)
- Onboard data handling (Marx J. 2011)
- Ground station control (Soyer 2011)

The goal of these studies is to investigate the feasibility and optimise the design of the system. The essential segments of the system will be described in Chapter 2. And this report will focus on the Ground Station segment.

The study of Ground Station (GS) has started since 2008. Long, the previous student of ASE analysed main drivers of the GS and made the preliminary architecture design. According to the drivers he evaluated Commercial Off The Shelf (COTS) both hardware and software, and summarized the candidate list for the GS. He also did trade-off for the site selection and pointed out that Building 52 is the best choice.

In 2010 Kawak took over the project. He focused on the wind drag analysis of the antenna mast and lightning protection system. He also suggested an optimized solution of the interface between the rotator controller and computer, which is the ERC-3D instead of PC-STATCTRL.

And later, Soyer finalized the design of GS. He studied antenna polarization and recommended polarization switches for the system to improve the signal to noise ratio. He also performed testing of the equipment and established a connection between two transceivers to simulate the packet radio communication. Furthermore, he studied mobile GS for high altitude balloon experiment. And he performed trade-off on choosing hardware and software for the mobile GS system.

1.2 Report Structure

This report consists of 8 chapters following the progress of the project.
Chapter1 tells the development of the Cubesat project and the background of this project, and then briefs the previous work done by each period of study. And also exhibits the overall structure of the report.

Chapter2 introduces the general Cubesat technology and application, and then shows the system and the functions of each segment.

Chapter3 describes the preliminary test. Firstly depicts the hardware and software used for the test and theirs configuration and connection method. Secondly explains the Cubesat communication by means of amateur radio and signal modulation. At last focuses on the test which includes the system setup, target selection, link analysis and the implementation of the test.

Chapter4 elaborates the finalisation of the ground station, including each hardware and software used. And then exposes the problems in remote control of the ground station and explains the solution.

Chapter5 deals the antenna mast support design. It exhibits the gradual improvement of the design from every analysis and suggestion.

Chapter6 focuses on the installation. Firstly analyses the risks during installation. And then describes the electrical connection in the aspect of device arrangement, cable assembly, antenna connection and tuning. After that states the mechanical installation process in general and emphasises some key points

of the installation. At the end shows the lightning protection and grounding system.

Chapter7 summarises all the work done to the project and briefs the progress of the project.

Chapter8 presents the suggestions and improvement that could be done to this project.

2 INTRODUCTION TO CUBESATS

The project started with literature review just as a normal start of a new project, but mainly focused on the three previous students' theses of their design and improvements. This chapter will first introduce the Cubesat concept, development and application, and then will focus on the GS segment; At last the related terminology will be explained.

From space mission point of view, any spacecraft successfully placed in orbit has to consist of three main segments: space segment, launch segment and ground segment. For a cubesat mission, though whole system is minimized if compared with traditional spacecraft mission, it also consists of these three segments: Cubesat (space segment), Ground Station (ground segment) and Launcher (launch segment).

2.1 Cubesat

Cubesat is a pico-satellite that is classified by its very low weight and size. It uses COTS components and needs much less development time and management effort than the traditional satellites Thus it is becoming more attractive to universities and companies for educational purpose and new technology testing. Cubesat increases the accessibility to space technology for wide people with less cost. Especially, it can get students involved through the Cubesat project development and management.

In 1999, CalPoly and Stanford universities proposed the standard of Cubesat. The standard size is 10cm x 10cm x 10cm cube, and weight is no more than 1.33kg**.** This is referred as 1 U (nit). There are two more sizes that are acceptable for the Orbit Deployer: 20cm x 10cm x 10cm (referred as 2U) and 30cm x 10cm x 10cm (referred as 3U). And this will be explained in Launch Segment.

Figure 2-1 1 A Cubesat in orbit (NASA website)

Same as any other operational satellites in space, a Cubesat also has its essential subsystems, such as:

- Mechanical Structures and Analysis (MSA)
- Attitude and Orbital Control Subsystem (AOCS)
- Electrical Power Subsystem (EPS)
- Telemetry, Tracking and Command Subsystem (TT&C)
- On-Board Data Handling Subsystem (OBDH)

These subsystems enable a Cubesat functioning on orbit, furthermore, able to carry out certain mission. Depending on the mission, and of course the budget, most of the components of the Cubesats were selected and purchased from COTS products. Through the previous missions show that the chosen COTS components have sufficient reliability and resolution, since most of the missions will not last for long and the main goal is for education. Another advantage is that Cubesats fly in Low Earth Orbit (LEO) at altitude less than 1000Km, and in this altitude there is less radiation effect on Cubesats.

Payload is another focusing point that should be carefully considered in order to carry out the mission, such as remote sensing, new innovation proven. The de-orbiting subsystem is the one that the current study is focusing on. As after mission the Cubesat should be removed from orbit and to avoid it to be space debris.

In conclusion, Cubesats are standardized pico-satellites on LEO. They are becoming more and more attractive to universities and small medium enterprises as its low cost and less development time compared to the traditional satellites.

2.2 Ground Station

Without ground station satellite will be a space junk. A functional ground station not only sends tele-command to control the satellite, but also receives telemetry from satellite. The simplest one will consist of PC, transceiver and antenna. The PC generates signal and stores the received data. Transceiver is used to transmit and receive signal, while antenna is to enhance the signal transmission and reception.

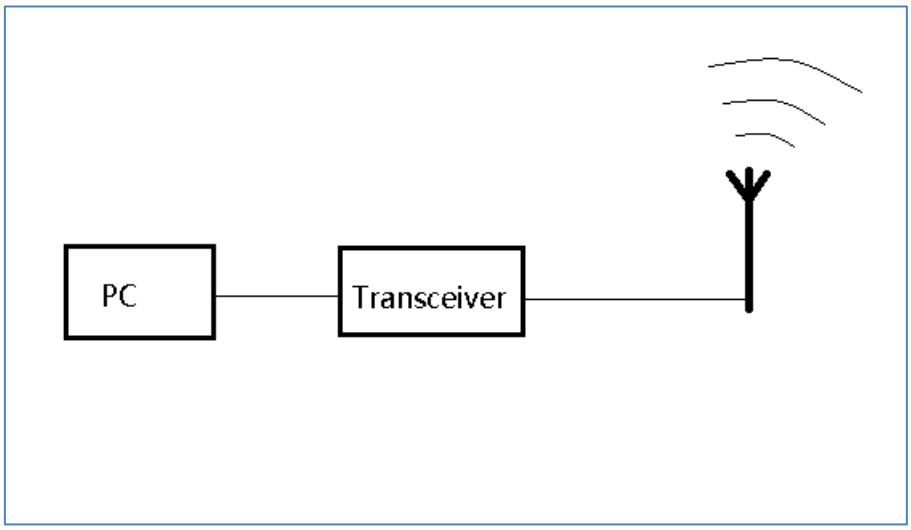


Figure 2-2 simple ground station illustration

2.2.1 Transceiver of a Cubesat Ground Station

As Cubesats communication link works in VHF/UHF band, and some work in S band. The transceiver of a Cubesat Ground Station should have same configuration in order to communicate with the satellite. Usually the commercial amateur radios with VHF or UHF, or duplex band are used as a transceiver at the Cubesat Ground Station. There are several radio brands are available on the market, such as YAESU, ICOM, KENWOOD, etc.

Figure 2-3 typical commercial radio (aprs.org website)

In Cubesat communication, one of the important factors is the transmitting power. The power range of these radios is from few watts to hundred watts. As the operation of an amateur radio needs a proper license and different license has certain limit of the transmitting power. In another words, the operator of the Cubesat Ground Station has to possess an amateur radio license.

2.2.2 Antenna for Cubesat Ground Station

Antenna is another important component in the GS. It converts the Radio Frequency (RF) signal into electromagnetic wave in free space, while keeps the same characteristics of the signal, which is referred to as reciprocity, regardless transmission or reception. An efficient antenna must be of following terms:

Impedance of the antenna, the radio and the connection cable must be the same. Typical impedance of the radio and connection cable is 50Ω. In order to keep the high performance of the antenna, and transmit or receive highest RF energy, the impedance of the system must be matched.

Return Loss measures the logarithmic ratio of the reflected power with the transmitted power that is fed to the antenna.

Beam Width is the angular distance of two points that have ½ power of the peak intensity on either side of the lobe. ½ power is -3dB in logarithmic scale, so this is also called 3dB beam width.

Gain is another logarithmic ratio of energy radiated in some direction compared with the energy radiated by a standard isotropic antenna at the same distance and transmitting power.

Band Width means the frequency range of the antenna that can be operated with expected performance.

Polarisation is determined by the vector of the electrical field in the electromagnetic wave. In general there are two types polarization: linear polarisation and circular polarisation. Linear polarisation means the electric field vector remains in one plane all the time. It includes vertical and horizontal polarisation with respect to the Earth ground. Vertical polarisation is always found from omni-directional antennas. The electric field vector rotates in a circular motion around the propagation direction in circular polarisation. Circular polarisation has two types polarisation: Right Hand Circular Polarisation (RHCP) and Left Hand Circular Polarisation (LHCP). It is called RHCP if the electric field vector rotates clockwise when looking at the propagation direction.

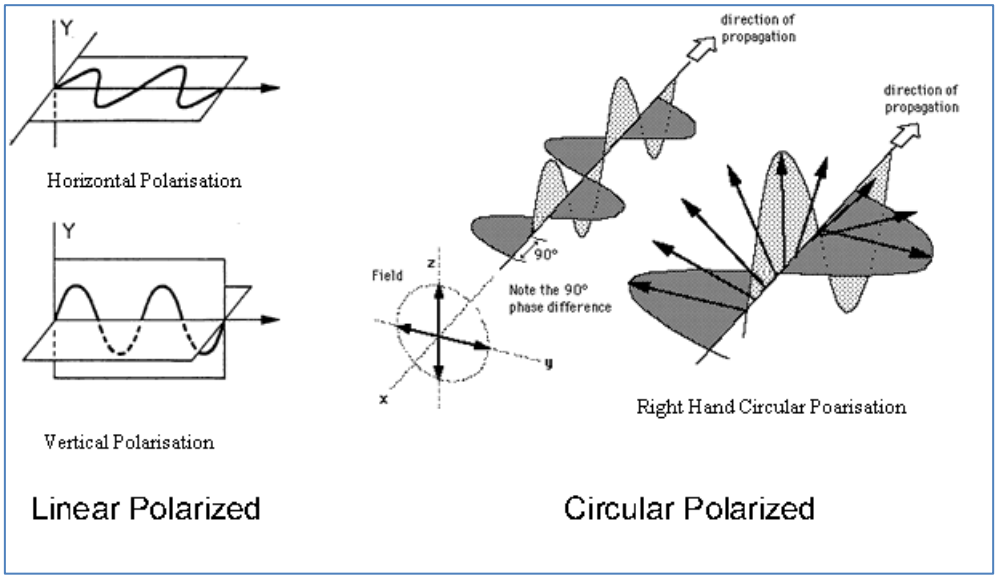


Figure 2-4 Electromagnetic wave polarisation [1]

Polarisation of the antennas at the both ends of the communication link path has to be the same, in order to get maximum signal strength. Otherwise, the signal strength will be degraded. For linearly polarised antennas, the signal

strength loss will be up to 3 dB if the misalignment of polarisation is 45 degrees. This can be calculated by equation

$$L_{Polarisation} = 20\log(\cos\alpha) \quad \textbf{(2-1)}$$

where $L_{polarisation}$ is in decibel, α is the misalignment angle. As α increases, there will be more polarisation loss Thus antenna polarisation is an important component has to be considered for the space communication link. Usually circular polarisation is used for space communication as this type of antenna polarisation has less influence on the link.

There are several types of antenna used for GS, commonly are the Yagi high gain antennas for VHF/UHF band and dish antenna for S band. As the power limitation on Cubesat, its transmitting usually is less than 1W. The antennas of a Cubesat ground station have to be directional in order to increase the reception capability, hence increasing the gain of the receiving signal.

2.3 The Launch and Deployment

As the market of launching Cubesat is increasing, a low cost and reliable launch vehicle is desired. Studies have been carried out for simplified and low cost launch vehicle.[2] Though it is a simplified system, it is still under development due to reliability and other matters. While at the moment Cubesats are launched by conventional launchers as secondary payload. Thus the cost is much less than the primary payload but depending on the launching availability.

A specially designed mechanism is used as the interface between payload and the launcher. Apart the standard of Cubesat, Cal Poly has also developed the specification for the interface which is named as Poly Picosatellite Orbital Deployer (P-POD). It has been flight-proven with a cost 40000$. The P-POD internal volume is 34cm X 10cm X 10 cm which can accommodate three Cubesats of 1U size or one Cubesat at 3U size.[3]

The P-POD is designed to be easily attached to the common launchers. There is only one connection to the launcher control computer, which is for the control of the door release mechanism of the deployer. When the launcher get into

assigned position of the orbit, the door of the deployer will be triggered to open electrically and the compressed spring will push the Cubesat out at a speed about 2 m/s.

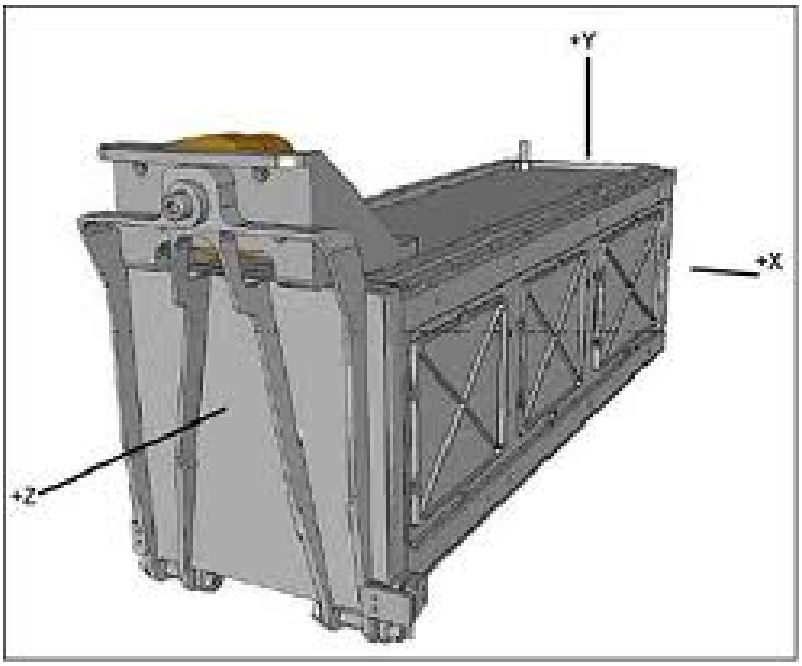


Figure 2-5 P-POD Mk. III

Beside P-POD, there are several orbital deployers which have also been flight-proven. Tokyo Pico-Satellite Orbital Deployer (T-POD) is the single satellite deployer that developed by Tokyo Institute of Technology. It has been used to deploy CUTE-I and XI-IV on orbit. eXperimental Push Out Deployer (X-POD) is designed by University of Toronto Institute. It can tailor with different size of satellite up to Nanosatellite. Single Pico-Satellite Launcher (SPL) has also been flight proven and manufactured by Astrofein. It was used to successfully deploy BEESat, Swiss-Cube and UWE-2.

2.4 Conclusion

Space is becoming more accessible for university students or small companies with comparatively low cost by means of Cubesat activities. The development of cubesat is not only for educational purpose, but also for new technology proving and remote sensing etc. The great advantages attract more and more people to get involved.

Ground station is the essential segment for Cubesat activities. Most of the Cubesat ground stations use VHF/UHF band for communication. And the COTS radio is often used as transceiver both for telecommand and telemetry. Thus operating a ground station the amateur radio license is needed.

As the antenna is the important component for communication, some critical factors have to be considered, such as the Impedance, Gain, Polarisation and Band Width. Usually circular polarised antennas are used for Cubesat ground station as they are less influenced by reflection and interference. No matter how, the final goal is to get as high a Signal to Noise Ratio (SNR) as possible. And then it is easier to establish the communication link with Cubesat.

Several obital deployers were developed and flight proven according to the need of launching Cubesats. P-POD is the most popular one which can accommodate one or in any combination of 1U up to 3U size of Cubesat.

3 PRELIMINARY TEST

This chapter firstly introduces the study and test of the equipments' connection and configuration. And then describes the analysis of communication link of the mobile system. At the end depicts the preliminary test from system setup, target selection to test results.

As works have been done to some equipments during last year, the inspection work must be performed before any connection and test. This is to ensure every device to work properly and minimize unexpected problem to happen. In this stage only indoor devices including software will be configured. The outdoor devices will be configured during final installation, such as VHF/UHF antennas and polarisation switch which is still under consideration to buy.

3.1 Hardware & Software Configurations

3.1.1 Ham Radio Deluxe

Ham Radio Deluxe is free amateur radio software invented by Simon Brown (HB9DRV). It consists of four integrated programs, of which three are of interest here.

They are the HRD Radio Control, HRD Satellite Tracking and HRD Rotator. They can be run separately, but in order to communicate with satellite, some functions have to be enabled among them, for example, Dynamic Data Exchange (DDE) for HRD Rotator Control.

3.1.1.1 HRD Radio Control with IC-910H

Most COTS radios provide Computer Aided Transceiver (CAT) capability which means that the radio can be fully or partially controlled by a designed program through Communication Interface-V (CI-V) system. In other words, the program from computer can write/read command to the controller of the radio through the CI-V interface. [4] The previous study shows that HRD is a good choice.

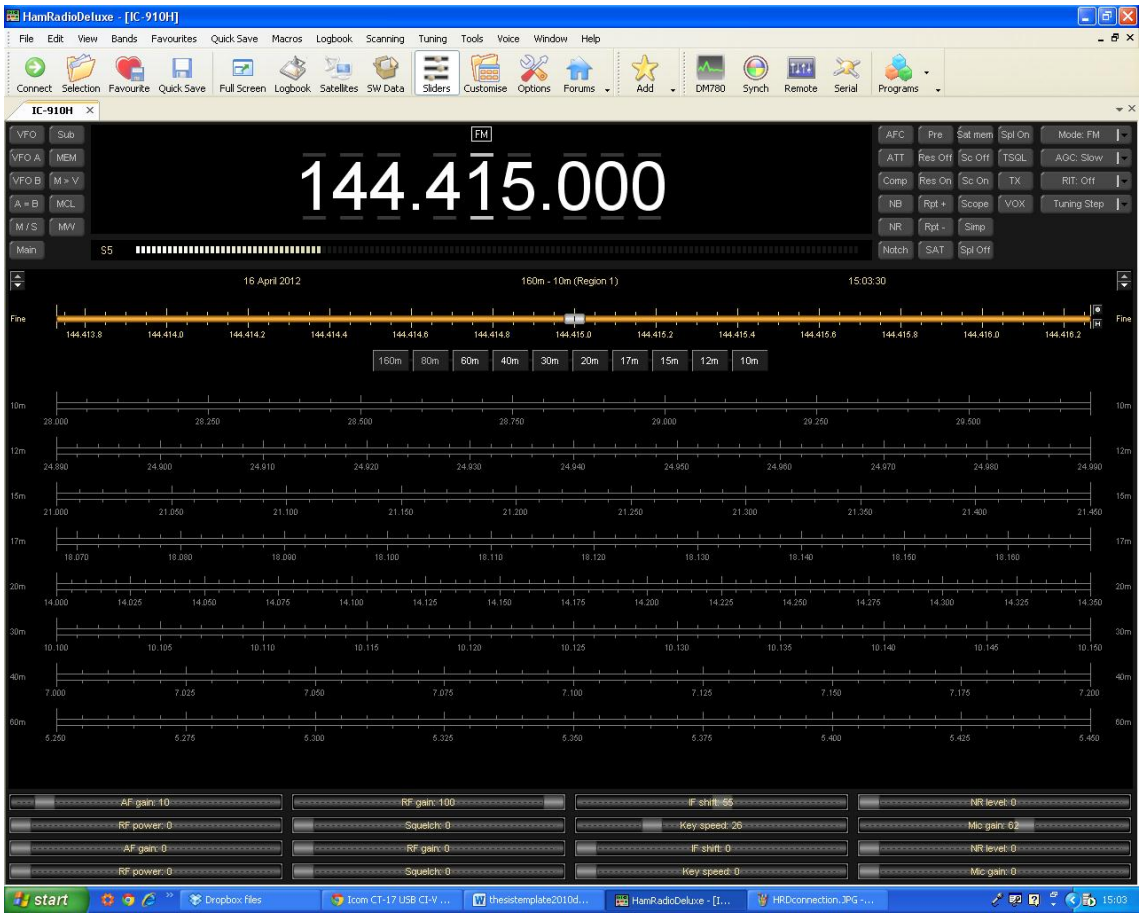


Figure 3-1 Control Panel of Ham Radio Deluxe (version 5.11).

From this control panel, frequency, mode, and the other parameters can be adjusted by mouse or keyboard. The original interface is CT-17 which uses FT232 chip to convert signal between radio and computer. Nowadays most computers don't have RS232C interface (named COM). For this GS, one USB CI-V CAT Control Cable is used to replace the original one. This cable emulates a Serial Port with USB which is the common connection. The port can be found from Device Manager when plugging in the cable to USB socket of computer. Then this port has to be selected in HRD Radio Control as the communication port with the radio. The connection parameter is set as below:

ICOM 910H to HRD Connection Setting	
Company	ICOM
Radio	IC-910H
COM-port	*check*
Speed	19200
CI-V	60

Table 3-1 ICOM 910H Connect to HRD setting

The COM-port has to be checked out depending on which USB port is used. 60 is the command address of the controller in the radio. When the radio is selected, usually it will prompt up automatically.

3.1.1.2 HRD Satellite Tracking

To determine a point in space relative to an object, first one coordinate system has to be defined. Geocentric Equatorial Inertial (GEI) coordinate system is a commonly used one. In this coordinate system, “z” axis is along the Earth rotation axis and define north direction is positive, and “x” is the line from the Earth centre to the Sun during vernal equinox, while “y” axis is the cross product of “z” and “x” which creates a right hand coordinate system.

Under the GEI coordinate system, the position of satellite can be determined by six Keplerian Elements.

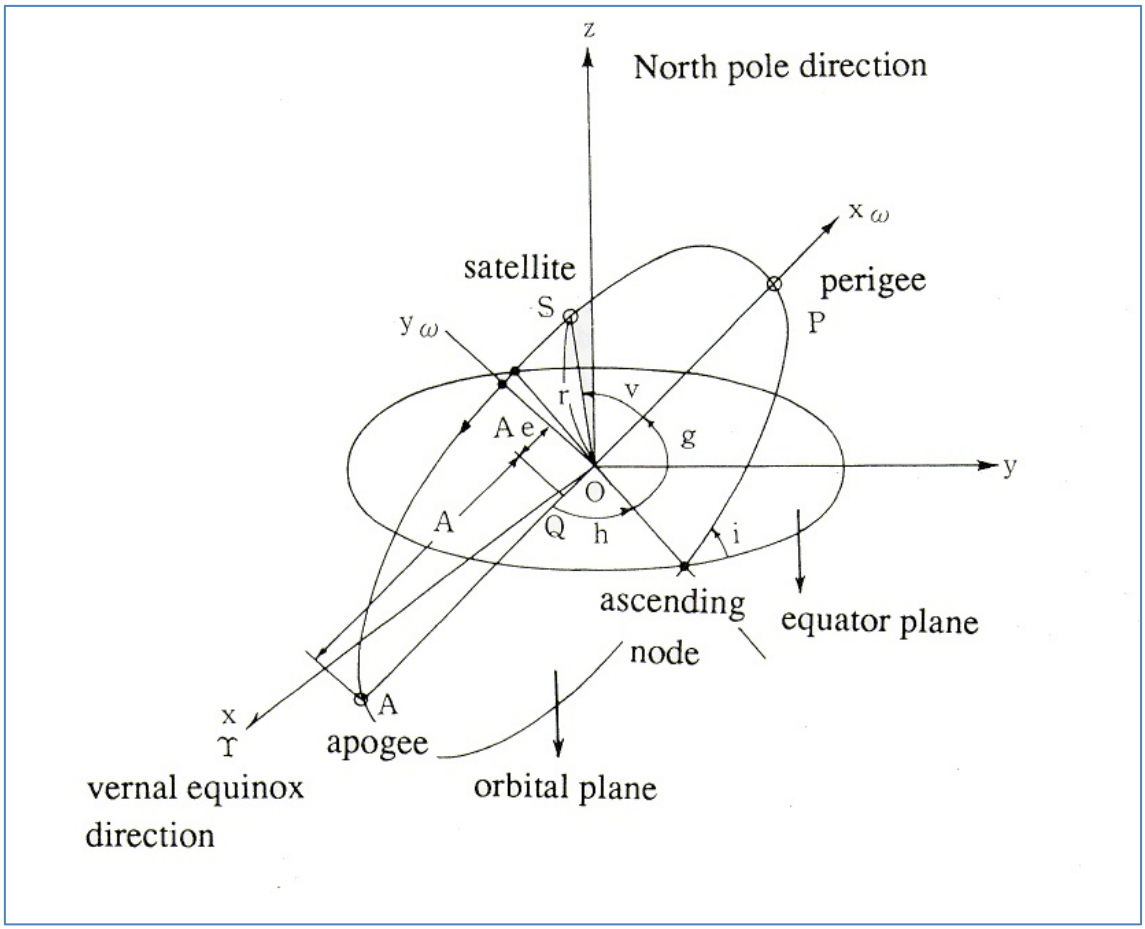


Figure 3-2 Six Keplerian Elements Illustration

1) A semi-major axis
2) e eccentricity of orbit
3) i orbit inclination
4) h right ascension of ascending node
5) g argument of perigee
6) v time of passage of perigee

“Q” is the ellipse centre, and “O” is the Earth Geometric centre. In the O-xyz coordinate system, first three parameters define the shape, size and position of the orbit, and last three define the orientation and position of the satellite.

HRD Satellite Tracking uses Two Line Elements (TLE) to calculate the position. TLE is a format describing satellite orbital parameters, including six Kelperian Elements. It can be found from Celestrak’s website. Actually the software

downloads the txt file of Kepler Data directly from Celestrak and Amasat. An example TLE of ISS is shown below:

```
ISS (ZARYA)
1 25544U 98067A   08264.51782528 -.00002182  00000-0 -11606-4 0  2927
2 25544  51.6416 247.4627 0006703 130.5360 325.0288 15.72125391563537
```

Table 3-2 Two Line Elements of ISS

Before starting tracking, the location has to be specified. **Your Information** can be found by following this path: **tools** > **options**. There are two main fields **Location** and **Height**. The Location can be expressed in two ways: **Locator** and **Longitude/Latitude**. **Locator** is from Maidenhead Locator System used for amateur radio, which doesn't give high accuracy. Locator **IO92QB** is for Cranfield. If it is filled in, the longitude/latitude which is the centre of Locator **IO92QB** will be automatically filled in. Hence it can not give high precision. For the Cranfield GS, **Longitude/Latitude** will be used and they can be measured by any Global Position System units at the place where the antenna is exactly placed. Then the readings 52°4.30'N and 0°37.69' can be filled in manually. The elevation of Cranfield is 109m which means the height above the mean sea level.

Now it can be used to predict the coming passages. The feature used is **Next Passes**. It can show one or multiple satellites' passage in Elevation, World Map or Radar format. And **Next Satellite** shows the satellite path on world map, including the time of Acquisition Of Signal (AOS) and Loss Of Signal (LOS), Range, Elevation and Azimuth etc. One very useful function it does is the Doppler Compensation while communicating with satellite, no matter transmitting or receiving signal. This makes the radio operation very convenient and smooth.

Moreover, HRD Satellite Tracking has embedded DDE server which provides the data needed for rotator control. Thus this function must be enabled in order to control the rotator.

3.1.1.3 HRD Rotator with ERC-3D

As mentioned above, HRD Rotator utilises the data calculated by the Satellite Tracking program based on the TLE, then generates control commands and sends to the rotator controller interface. As the control computer can not directly communicate with the Rotator Controller, an interface is needed.

Easy Rotator Control (ERC-3D) is chosen as it is compatible with protocol Yeasu GS232 which is used by G5500. It can control both azimuth and elevation, meanwhile reads the feedback voltages from rotator and send to computer for indication.

ERC-3D was separate parts as ordered at the beginning, and was assembled during the previous project work. Then it was checked by the inventor who confirmed it is functioning. Thus only work done was to refine the soldering of components on the PCB and fixe it in an enclosure.

Wiring was fully checked and fixed according to the Installation Guide.[5] There are two connections: one to computer and another to Rotator Controller.

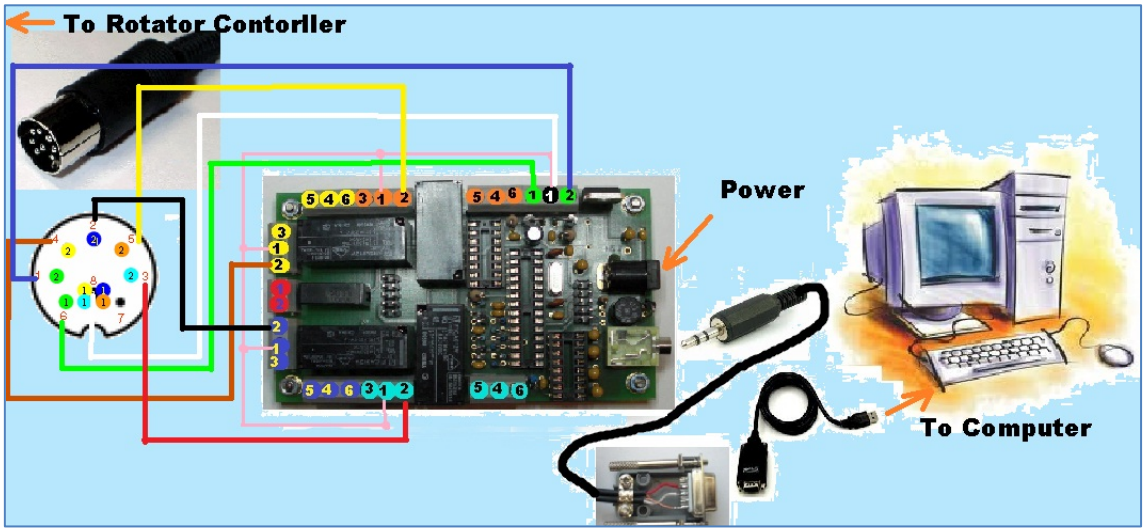


Figure 3-3 ERC-3D Wiring Illustration

- **From 3.5mm Stereo Phone Jack to Computer** is a three wires audio cable: one end is normal plug and another end is adapted to RS232 connector which can be connected to computer by another USB cable.

- **From ERC-3D to Rotator Controller** is a 7-core cable with 8-pin DIN connector (pin7 is not in use). The wires with different colour inside the cable are assigned to one for common ground, four for four relays control and two for voltage feedback. Common grounds are connected together shown in Figure 3-3 above in pink colour line. Detailed connection is shown in Table 3-1below:

ERC-3D Terminals Connection		
ERC-3D PCB Terminals	**DIN Connector Pin no.**	**7-Core Cable Wire Colour**
	8	White
	6	Green
	1	Blue
	2	Black
	4	Brown
	3	Red
	5	Yellow

Table 3-3 REC-3D Terminals Connection

When connect USB cable to computer, the port have to be checked which will be used for configuration. The configuration of connection is shown Table 3-4 below

ERC-3D to HRD Connection Setting	
Rotator	Yeasu GS-232B Az/El
Port	*check*
Speed	9600
Refresh Rate	1sec
Stop Position	North 360°
Call sign	CRANSAT
Country	England
Locator	IO92QB

Table 3-4 ERC-3D to HRD Rotator settings

If UBS cable is plugged to other port of the computer, then the port has to be checked out again as the Serial to USB converter emulates port without fixation.

3.1.2 Rotator Controller to Azimuth & Elevation motor

Yaesu G5500 Rotator Controller controls both Azimuth and Elevation motor through two 7-wire cable. The cable has one end connected to the Controller Screw Terminal and another end connected to motors with 7-pin DIN plugs. According to its Operating Manual, pin 7 is not used and the rest pins were connected to wires with different colour. Brown colour wire was assigned not to use.

Rotator Controller Cable Connection	
Pin No.	Wire Colour
1	Red
2	Green
3	Yellow
4	White
5	Blue
6	Black
7	Brown

Table 3-5 Rotator Controller Cable Connection

3.1.3 Terminal Node Controller Connections

Terminal Node Controller (TNC) is used in Cubesat packet radio communication, which enables digital signal transmission through electromagnetic wave. It consists of microcontroller, modem and embedded software that implements AX.25 protocol.

The one used in Cranfield GS is KPC-3+, which is a single port radio modem compatible with VHF/UHF band communication. Combining with a VHF/UHF radio transceiver, it is achievable to remote control satellite and receive telemetry.

Usually a TNC has at least two modes. “Command mode” allows user to configure parameter settings to optimize its performance. While in “converse

mode” is to send or receive packet data. Nowadays, as computer processors become more powerful, some signal processing functions have been removed from TNC to computer. Several protocols were developed to achieve this goal, and the most common one is the “KISS” mode (Keep It Simple Stupid). Based on this mode, much functional and powerful software have been developed based on computer operation system. They work in a way that once software run on computer then the “KISS” mode will be activated on TNC. In fact, KPC-3+ supports a so called “XKISS” mode which is the Extended “KISS” mode. It works same as “KISS” mode, but one more function is to connect to G8BPQ node along with the other TNCs that on the same serial ports, to provide more radio ports to the node.[6]

The signal processing path is: first, the software on computer generates digital signal then send to the TNC; second, the TNC modulate the received signal from computer and send to transceiver; at last, transceiver transmits signal and emit through antenna, vice versa. KPC-3+ has two terminals: DB-25 and DB-9. Terminal DB-25 is connected to computer by a serial to USB converter cable and terminal DB-9 is to radio by a customized cable. The connection diagram is shown Figure 3-4 below

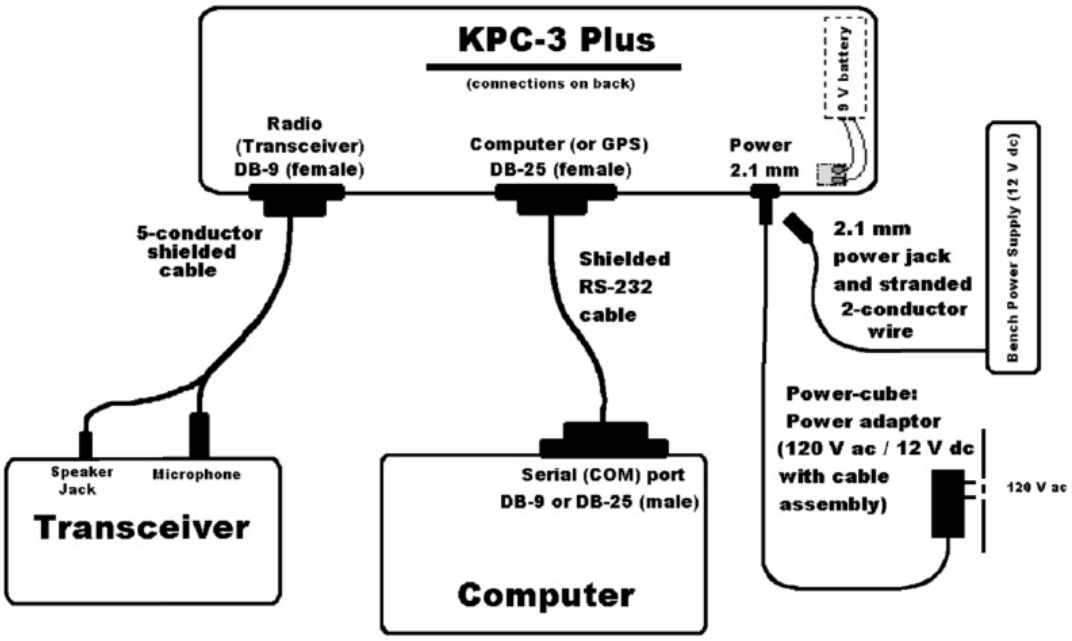


Figure 3-4 KPC-3+ connection diagram [6]

3.1.3.1 KPC-3+ to Computer (Hyper Terminal)

The 25-pin D-sub can not be connected to computer directly as the current computer doesn't support it. Hence a DB-25 to DB-9 adapter was used which was then connected to computer by a serial to USB converter cable. So far, there are three of these USB cables connected to the control computer. Same as what was done before, every time the ports from which is connected to the computer have to be checked out.

The connection configuration was done with the help of Hyper Terminal (HT) which is an integrated program in Windows XP. The port connection settings in HT is shown as in Table 3-6 below

KPC-3+ to Hyper Terminal Connection Setting	
Bits per second	9600
Data bits	8
Parity	None
Stop bits	1
Flow control	Hardware

Table 3-6 KPC-3+ to Hyper Terminal setting

Once connected, TNC will go to “command” mode in HT. It will go to “convers” mode by typing k and enter. Under this mode, HT can display received message or send out typed message. If there is any signal from TNC to HT, and then it will go to “convers” mode automatically and display the decoded message. By pressing combination key “Ctrl + c” it will go back to “command” mode again. In fact, first time connect TNC to HT or after hard reset, the AUTOBAUD will be performed, which will auto detect communication rate if matches with port setting. If matched, then the message is readable. Otherwise, it will be garbled

3.1.3.2 KPC-3+ to ICOM 910H Connection

The connection between TNC and radio is a customised cable that one end with DB-9 male connector and another end is a 6-pin mini DIN plug.DB-9 has 9 pins of which four are wired to four of the 6-pin DIN connector. The wiring connection is indicated in Table 3-7 below

pin no. of DB-9	connect	pin no. of 6-pin DIN connector
P.1 TXA Transmit audio (AFSK out)	⟷	P.1 DATA IN
P.3 PTT Push-to-Talk	⟷	P.3 PTT
P.5 RXA Receive audio (AFSK in)	⟷	P.5 AF OUT
P.6 GND Ground	⟷	P.2 GND

Table 3-7 Connection cable to ICOM 910H radio [4]

This connection is intended to use DATA socket on the radio for 1200 bps operation. The radio also provides 9600 data rate by using pin 4 of 6-pin DIN mini connector instead of pin 5. As the TNC only support 1200 baud operation,

the lower operation speed was chosen. As a matter of fact, this connection configuration can be used for another radio: YAESU FT-817 which has the same DATA socket configuration as the ICOM ones.

3.1.4 AGW Packet Engine & Monitor

AGW Packet Engine (AGWPE) is a packet computer program written by Radio Amateur SV2AGW. It can do packet function with external TNC in “KISS” mode or “XKISS” mode. This program works in VHF at 1200 baud and UHF at 9600 baud operation. It is compatible with other programs, such as AGWTERMINAL, AGW Monitor.

AGW Monitor is a program that monitors all packet activities on AGWPE and displays the decoded message. Once AGWPE is configured, the ports that AGWPE operates will automatically show up on AGW Monitor.

The configuration of AGWPE is easy as it is based on HT’s configuration. This means it has the same basic configuration as HT’s but more detailed options. The options were customised to a set that is just to select the proper option then the corresponding parameters will be automatically filled in.

The configuration was done in **Properties** by right clicking of mouse on the program icon. Parameters were selected as Table 3-8 below

AGW Packet Engine Properties	
Select Port	*check*
SerialPort/modem BaudRate	9600
Tnc RadioPort	fill in
Tnc Type	KPC3+

Table 3-8 AGW Packet Engine Properties

Tnc Radio Port can be filled in based on frequency and baud rate, e.g. *145.650Mhz 1200baud.*Once **Tnc Type** is selected, then the rest blanks will be automatically filled in.

There is no need to configure AGW Monitor. Once AGWPE is configured and run, the ports will be shown in Monitor automatically. The same rule applies to AGWTERMINAL which is used to receive and transmit packets.

3.2 Cubesat Radio Communication

The theoretical study of the Cranfield GS has been lasting for a long time. During last stage, the architecture of the GS was finalised and some functions were tested. In the current stage, before implementing the GS, it is required to demonstrate the reception of any Cubesat beacons by using a minimum system. This is the way to verify the theoretical design and operation. Considering the convenience and current status of the GS, a small mobile system was built for the test. Before test, the link budget was analysed.

3.2.1 Amateur radio frequencies & modes

Although many frequency allocations which are controlled by the International Telecommunication Union (ITU) and regulation of countries were assigned for amateur satellite service, Cubesat commonly use VHF and UHF band, some use S band for higher data rate. This is because of the easy implementation and convenience of operation, which means that those who have an amateur radio license are allowed to operate the Cubesat GS.

- VHF (144 MHz – 146 MHz) Very High Frequency, which is often referred as 2m band is planned for uplink
- UHF (430 MHz – 440 MHz) Ultra High Frequency or called as 70cm band, will be used for downlink.
- S band (2.3 GHz – 2.5 GHz) is also called 13cm band supporting data transmission rate up to 115kbps.

3.2.2 Modulation and protocol

In telecommunication, modulation is the process of conveying message signals buried inside the carrier by varying its amplitude, frequency, phase and polarisation [7]. For amateur radio communication, generally there are two main types of modulation: analogue modulation and digital modulation. Commonly used modulations on amateur radio are: CW, AM, FM, SSB, PSK, FSK and AFSK.

In **analogue modulation**, the input message signal is modulated continuously. Modulations belong to this group are:

AM: Amplitude Modulation conveys message signal by varying its amplitude according to the instantaneous amplitude of the modulating signal.

SSB: Single Side Band is the refined AM using power and bandwidth with higher efficiency as AM results doubled bandwidth than the input baseband signal. It has two cases: the band below carrier frequency is called Lower Side Band (**LSB**) and above the carrier frequency is named as Upper Side Band (**USB**), which are shown in Figure 3-5 below:

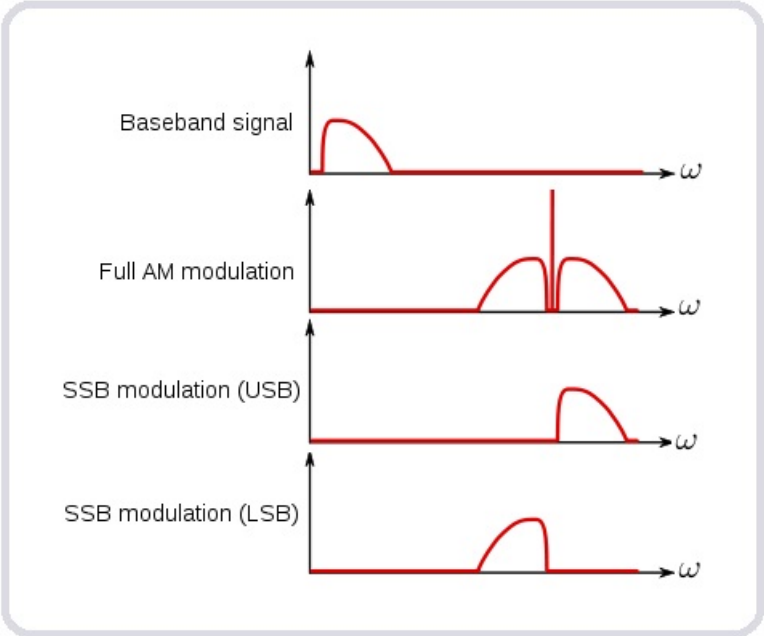


Figure 3-5 Single Side Band, Upper Side Band and Lower Side Band (adapted from Wikipedia)

FM: Frequency Modulation is to vary the frequency of the message signal instantaneously over the carrier. .

In **Digital modulation,** the properties of carrier signal are varied by a binary codes stream.

CW: Continuous Wave is the carrier wave with constant frequency and amplitude is switched on/off during transmission. The most well-known one is Morse Code which is widely used for beacons in Cubesat application.

PSK: Phase Shift Keying uses phases of the constant carrier signal to represent 0 and 1 binary codes.

FSK: Frequency Shift Keying uses one frequency of the carrier to represent “0” and another frequency to represent “1”.

AFSK: Audio FSK utilizes the changes of the frequency of audio tone to represent binary data and then transmitted in FM. Normally, tone at 1200Hz is assigned for marker “1” and tone at 2200Hz is assigned for space “0”, this is applied under Bell 202 Standard. In AFSK mode, typically transmission rate is 1200 baud, about 150 characters per second.

According to ICOM’s user manual, 910H radio is able to operate in CW, LSB, USB and FM mode. Under FM mode, it can transmit and receive AFSK packet signals if it is connected to TNC (KPC-3+ in this case). While the portable transceiver FT-817 has more modes capabilities, e.g. AM, PKT-31, but only AFSK under FM mode and CW are of interest for Cubesat communication.

Common Cubesat data communication is AFSK with AX.25 protocol implemented. AX.25 protocol is developed from X.25 protocol for amateur radio packet transmission. In packet transmission data is sent in small segment which is called “packet” or “frame”. There are three types of frame: information frame (I frame), supervisory frame (S frame) and unnumbered frame (U frame). Each frame has several fields that shown in Figure 3-6 below [8].

Flag	Address	Control	Info	FCS	Flag
01111110	112/224 Bits	8/16 Bits	N*8 Bits	16 Bits	01111110

U and S frame construction

Flag	Address	Control	PID	Info	FCS	Flag
01111110	112/224 Bits	8/16 Bits	8 Bits	N*8 Bits	16 Bits	01111110

I Frame Construction

Figure 3-6 frame construction in AX.25 protocol

A frame starts with flag and header and ends with checksum and flag. Flag is a specific number indicating start and end of a frame. A header tells the origin and destination of a frame. Checksum is the number produced based on the characters in the frame by mathematical method. The number will be recalculated in the receiver. If doesn't match, the frame will be aborted.

Ax.25 protocol is embedded in the firmware which is written in EPROM of the microcontroller of the TNC. During packets transmission TNC assembles or disassembles the data and then sent to computer or transmitter.

3.3 Test

As mentioned previously, a mobile GS is desired for testing the reception of beacons from any Cubesat or amateur satellite. In principle, ICOM 910H should be used for the testing as it is the main radio in the Cranfield GS. But it is heavy and requires external battery which is not handy for outdoor testing. After a short study it was found that FT-817 can be connected to KPC-3+ for outdoor testing without any modification.

3.3.1 Mini System Construction

No matter the size of a GS system, it must have antenna and transceiver. Later after starting the project, another omni-directional antenna (SQBM110P MkII DUAL BAND 2/70 VERTICAL) was purchased for testing. For packet radio, TNC is also an essential device. Thus this mini system consists of FT-817 (transceiver), Omni-directional antenna and KPC-3+ which is used for packet radio only. The connection setup is shown as Figure 3-7 below:

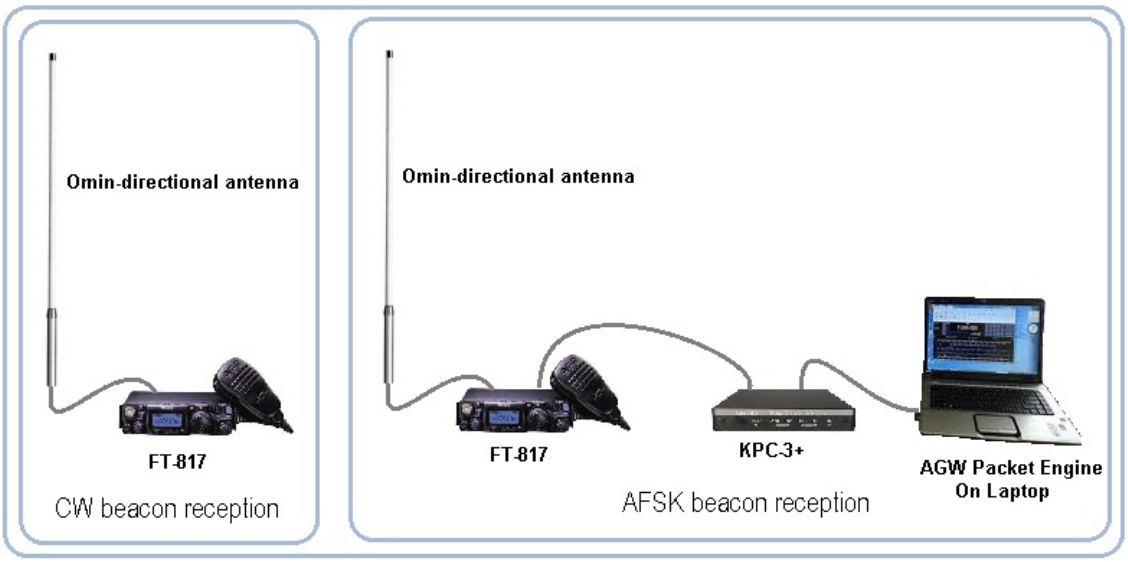


Figure 3-7 CW & AFSK Beacon Reception Setup

For the convenience of outdoor testing, the radio will be operated by internal power. TNC also has the possibility to use internal battery but need slight modification. According to its user guide, a battery clip with two wires was soldered to its PCB. Thus TNC can be powered by a 9V battery for outdoor use. Because there is no YAESU CT62 CAT cable, the radio can't be controlled by the computer. Hence, Doppler Effect has to be manually adjusted for this GS.

3.3.2 Targets Selection

Cubesats' beacons contain a lot of useful information. They can provide not only on-board status but also help the tracking. Moreover, beacons can be used as gauge of signal strength which will help the optimisation of link budget of the GS.

As the power is limited on Cubesat, usually the power of beacon transmitter is less than 1W. Anyway, the higher the power of the transmitter, the better signal for reception. There are a few criteria of selecting Cubesats for testing:

- Target must be currently operational
- Continuous beacon is better
- Higher beacon transmitting power

- Beacon information has been published, the better with decoding software.
- Higher availability upon testing place
- Beacons are sent in CW or AFSK mode

Based on above criteria, a Cubesats list was made for testing, which is shown in Table 3-9 below:

Satellite List for Testing				
Satellite	Frequency	Power	Modulation	Baud Rate
CO-55	436.8375MHz 437.470MHz	100mW 350mW	CW AFSK	50 WPM 1200bps
CO-57	436.8475MHz 437.490MHz	80mW 1W	CW AFSK	50 WPM 1200bps
CO-58	437.465MHz 437.345MHz	80mW 1W	CW AFSK	50 WPM 1200bps
CO-65	437.275MHz 437.475MHz	100mW 300mW	CW AFSK	50 WPM 1200bps
HO-68	435.790MHz	**200mW**	CW	50 WPM
ARISS	145.825MHz	>1W	AFSK	1200bps

Table 3-9 Satellite List for Testing (extracted from [9])

It can be seen that HO-68 has more power on beacon transmitting, thus it will be the prior candidate and the rest will be as backup. This decision is made for CW testing only. For packet radio, with this mini system setup, it is not possible to get any signal from Cubesat as the SNR is less than the required. Fortunately, as suggested by Soyer [10], ISS is a good candidate for packet radio reception testing, as it has much higher transmitting power in AFSK 1200 baud and the altitude is lower.

3.3.3 Link Budget Analysis

In order to receive the signal from Cubesat, there must be sufficient SNR for the radio. The sensitivity of FT-817 is 10 dB in CW mode. For AFSK mode, it is required to be at least 24 dB if the Bit Error Rate (BER) is 1.6×10^{-5} [11]. Table 3-10 below shows the relationship between BER and SNR, which can be seen

clearly that BER changed very much with a few dB difference of SNR. This table was produced based on an experiment done by a radio amateur [12].

BER		Eb/No (dB)	BPR
1.6x10^-5	0.0016%	24.0	99.998%
1.0x10^-4	0.01%	22.5	99.99%
1.0x10^-3	0.1%	19.5	99.9%
1.0x10^-2	1.0%	17.5	99%
1.0x10^-1	10.0%	15.5	10%

Table 3-10 Bit Error Rate & Eb/N0 & Bit Probability of Reception

From above table we can see that lower BER requires higher Eb/No. In order to get higher Eb/No, several parameters can be adjusted to improve the communication link. The relationship of these parameters can be expressed by a link equation:

$$E_b/N_o = \frac{P_t L_l G_t L_s L_o G_r}{k T_s R} \quad \textbf{(3-1)}$$

where E_b/N_o is the energy-per-bit to noise-density ratio, P_t is the transmitter power, L_l is the cable line loss, G_t is the gain of the transmitter antenna, L_s the space loss, L_o is the other losses, such as polarisation mismatch, antenna pointing error, atmospheric and rain attenuation etc., G_r is antenna gain of receiver, k is Boltzmann constant, T_s is the system noise temperature, and R is the data rate.[7] This equation can be rewritten as below if every parameter is expressed in decibel:

$$E_b/N_o = \mathrm{P} + L_l + G_t + L_s + L_o + G_r + 228.6 - 10\log T_s - 10\log R \quad \textbf{(3-2)}$$

where E_b/N_o, L_l, G_t, L_o, G_r are in dB, T_a is in K, P is in dBW and R is in bps, while 228.6 is given by $-10\log(1.38\times10^{-23})$.[7]

Equation for space loss L_s expressed in dB is:

$$L_s = 32.45 + 20\log S + 20\log f \quad \textbf{(3-3)}$$

where S is the distance from transmitter to receiver in Km and f is the radio wave frequency in MHz. The actual communication distance is the distance from Cubesat to GS. For a Cubesat with altitude roughly at 800Km, the longest

distance is considered as when the elevation angle is just 10 (minimum angle for communication link). The situation is illustrated as Figure 3-8 below:

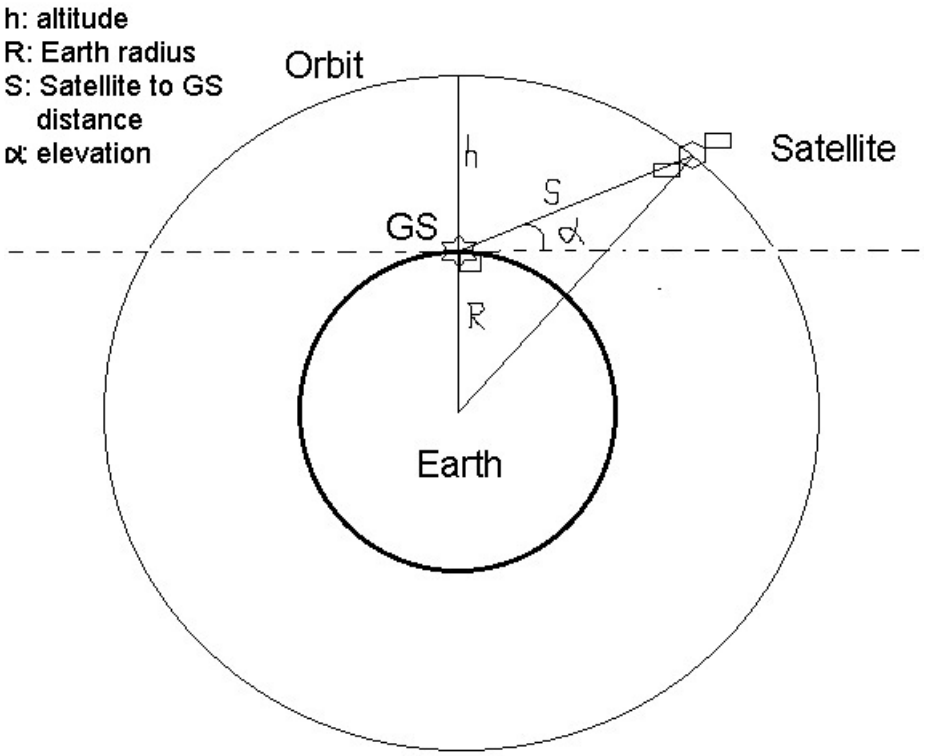


Figure 3-8 Free Space Loss Illustration

The distance S can be calculated by Cosine Theorem, and then S can be expressed as follows:

$$S = R\left(\sqrt{\left(\frac{R+h}{R}\right)^2 - (\cos\alpha)^2} - \sin\alpha\right) \quad \textbf{(3-4)}$$

Where R is the Earth radius, h is the satellite's altitude, α is the elevation angle (10° in worst case). Thus, for a 800Km altitude with elevation 10° relative to the GS, the longest distance is S=6378*(sqrt((7178/6378)^2 –cos^2(10))-sin(10))=2366Km.

Signal losses due to antenna pointing error can be calculated by formula:

$$L_\theta = -12(e/\theta^2) \quad \textbf{(3-5)}$$

where θ is 3dB beam width, e is the pointing error. 3dB beam width is specified in X-Quad's user manual and pointing error can be found from Yaesu G5500's user manual. They are listed in the Table 3-11 below

Antenna	3dB Beam Width	Yeasu G5500 Pointing Error	Pointing Error Loss L_θ
2m X-Quad	Horizonal:47 Vetical: 46	5	-0.027161612
70cm X-Quad	Horizonal:36 Vetical: 36	5	-0.046296296

Table 3-11 X-Quard beam width and G5500 pointing error with calculated pointing error loss

Attenuation due to atmosphere and water vapour is negligible when the link frequency is below 1000MHz. All the losses will be deducted from antenna gain. Receiver temperature is assumed at 290K and antenna temperature is 150K as it sees sky, the sun and other noise. Higher data rate requires higher SNR. Typical CW operates at 50WPM which is about 41.5 baud. Link analysis of CW and AFSK beacon reception is shown in Table 3-12 below:

Transmitter	Symbol	Units	CW Downlink	AFSK Downlink 1	AFSK Downlink 2
Link Frequency	f	MHz	435.79	145.825	437.345
Transmitter Power	P_{tx}	Watts	0.2	2	0.1
Transmitter Power	P_{tx}	dBW	-6.99	3.01	-10.00
Antenna Gain	G_{tx}	dB	3.00	3.00	3.00
Antenna Transmitter Losses	L_{tx}	dB	1	-0.5	-0.5
Antenna Beam width	θ_{tx}	Deg	45.0	180.0	180.0
Antenna Misalignment	α_{tx}	Deg	3	5	5
Alignment Loss	$L_{\theta tx}$	dB	-0.05	-0.01	-0.01
Equivalent Isotropic Radiated Power	EIRP	dBW	-3.04	5.50	-7.51
Losses					
Propagation Path Length	S	Km	3132.0	2366.0	3132.0
Space Loss	L_s	dB	-155.15	-143.20	-155.15
Atmospheric	L_a	dB	-0.01	-0.1	-0.1
Polarization Mismatch	L_p	dB	-3	-3	-3
Total Losses	L	dB	-158.16	-146.30	-158.25
Receiver					
Antenna Gain	G_r	dB	6.0	3.0	3.0
Antenna Receiver Loss	L_r	dB	-0.5	-0.5	-0.5
Antenna Beam width	θ_r	Deg	180.0	52.0	52.0
Antenna Misalignment	α_r	Deg	1	4	4
Alignment Loss	$L_{\theta r}$	dB	0.00	-0.07	-0.07
Total Receiver	G	dB	5.50	2.43	2.43
System Noise Temperature	T_s	K	440	440	440
Receiver Merit	G/T	DB(1/K)	-20.93	-24.01	-24.01
Rates					
Data Rate	R	Bps	4.15E+01	1.20E+03	1.20E+03
Eb/No	E_b/N_o	dB	30.28	33.00	8.05
Required Eb/No		dB	10	10	24
Required Margin		dB	5	5	5
Margin		dB	15.28	18.00	-20.95

Table 3-12 Link Budget of CW & AFSK test

It can be seen from above table that Eb/No in AFSK Downlink2 of CO58 is lower than required 24dB. In fact, with the mini system is not able to receive packet radio from CO series Cubesat.

3.3.4 Test Implementation

CW beacon reception test was the first then continued by packet radio test. Before starting the test, a test schedule was made by HRD Satellite Tracking. Only elevation that was bigger than 80° was selected as it might have strong signal during pass over.

Although HRD Satellite Tracking has been configured at the beginning, to be more precise for prediction, GPS coordinate was measured at the testing place. The testing place is a large sports field in front of the Cranfield Campus Main Reception. This place was selected as it is in campus and wide area without tall obstacles. Hence coordinate was measured in the centre of the area, which are 52°4.50'N and 0°3.89'W.

3.3.4.1 CW beacon reception and decode

HO-68 (alternative name Xiwang-1 or Hope-1) was launched by CZ-4C rocket on 15th December 2009 in China. It is Oscar microsatellite with Callsign BJ1SA. At the moment only beacon transmitter is still operational. CO series stands for Cubesat Oscar, which were developed by Japanese institutes. The size range is from 1U to 3U and all of them are still operational both in beacon and telemetry [13].

As mentioned in Target Selection, HO-68 was the primary candidate for the test while CO series were as secondary target. Moreover, more targets can provide more practice of real time radio operation for beginner. Passage with high elevation usually happens once a day. Actually CO series Cubesats appeared very often sometimes came with adjacent time slot. Thus operation practice of radio started with CO series Cubesats, e.g. CO-65. The software predicted next pass over was in the morning of 1st March from 10:23 (AOS) to 10:40 (LOS).

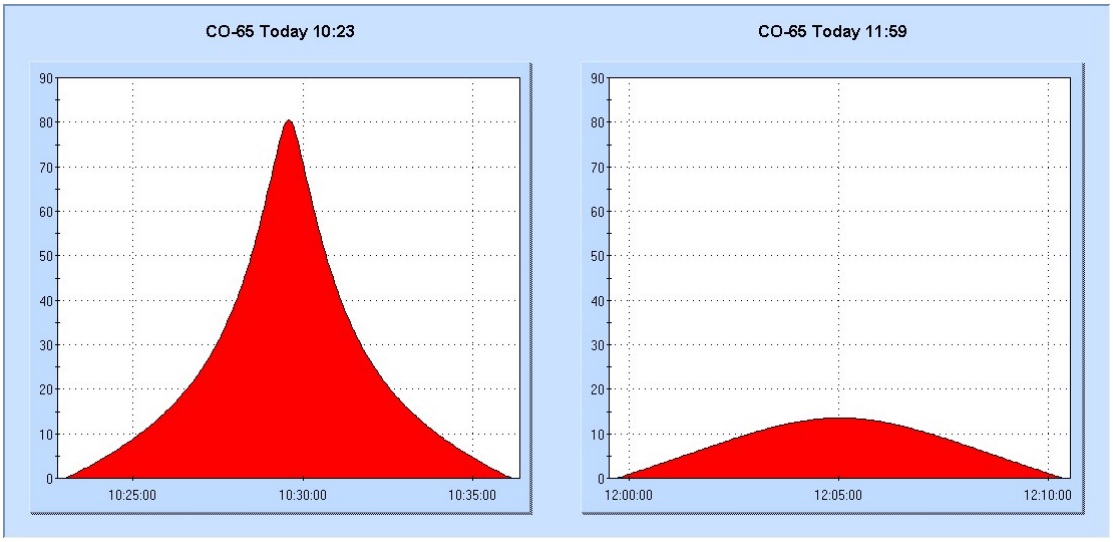
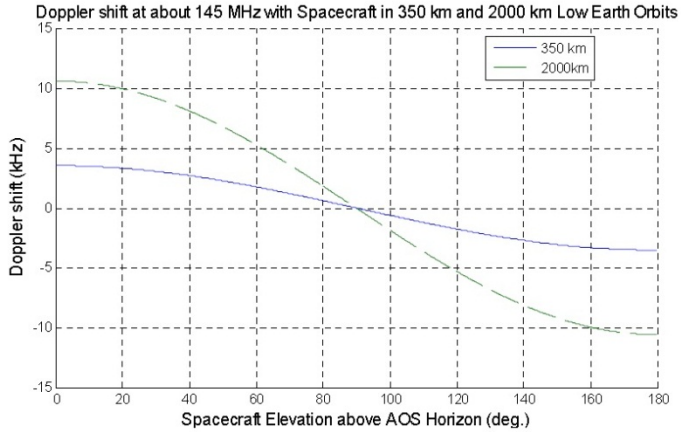


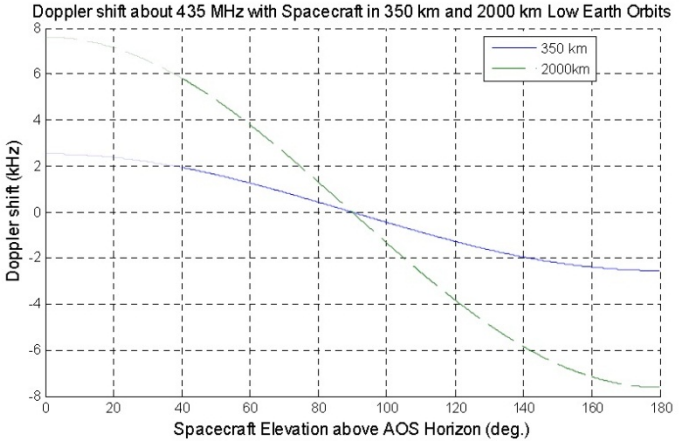
Figure 3-9 CO-65 Passage On 1st March morning

When operating the radio, one important effect encountered was the Doppler Effect. Doppler Effect is the change in frequency of radio wave as a result of relative movement between source and observer. This phenomenon arises when Cubesat is transmitting radio wave to the GS while it is orbiting around the Earth. This results a higher frequency ahead of the Cubesat in the direction of its velocity vector and a lower behind.

An alumnus, Long, who first started this project has analysed the Doppler frequency correction for the Cubesat communication. Doppler Correction or compensation is dependent on Cubesat orbital parameters, link frequency and required minimum elevation. He calculated the Doppler Shift range for satellites orbit from 350Km to 2000Km, operating frequency at 145MHz and 435MHz [14].


Doppler shift at about 145 MHz with Spacecraft in 350 km and 2000 km Low Earth Orbits
350 km
2000km
Doppler shift (kHz)
Spacecraft Elevation above AOS Horizon (deg.)

145MHz Elevation (deg)	Doppler Shift (kHz) 350 km	2000 km
1	3.529	2.834
5	3.521	2.827
10	3.486	2.799
…	…	…
170	-3.486	-2.799
175	-3.521	-2.827
179	-3.529	-2.834


Doppler shift about 435 MHz with Spacecraft in 350 km and 2000 km Low Earth Orbits
350 km
2000km
Doppler shift (kHz)
Spacecraft Elevation above AOS Horizon (deg.)

435MHz Elevation (deg)	Doppler Shift (kHz) 350km	2000km
1	10.590	8.503
5	10.560	8.402
10	10.460	8.398
…	…	…
170	-10.460	-8.398
175	-10.560	-8.402
179	-10.590	-8.503

Figure 3-10 Doppler Shift for orbit 350Km and 2000Km operating at 145MHz and 435MHz analysed by Long [14]

The targets are orbiting around the Earth at about 800Km altitude. From right bottom of the above figure it can be seen that the Doppler Shift is about 9KHz for 435MHz link at elevation 10. Actually, the radio was set to 4KHz above the standard frequency, e.g. HO-68 transmitting frequency is at 435.790MHz. The radio was set to 435.794MHz and then waited for AOS, which means the Cubeast had a higher elevation. This was proved during operation. Once received the signal then the frequency has to be adjusted continuously during the about 10 minute's operation time, otherwise the tone will fade out then the signal could not be heard and decoded. After one week practice, the Doppler Shift compensation was managed well during operation. Following the predicted schedule by HRD Satellite Tracking, in the evening of 9th March 2012, CW signal from HO-68 was heard and recorded.

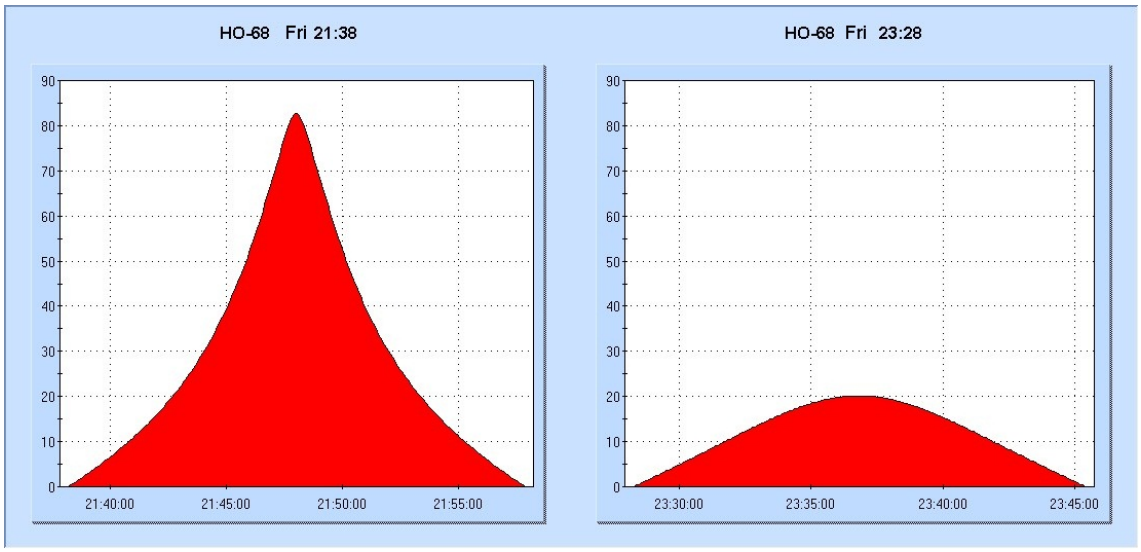


Figure 3-11 Predicted HO-68 time slot

The frequency when the signal segment was recorded is from 435.784MHz to 435.781MHz. The tone was so clear when close to 435.781MHZ that it was decoded by Morse Code Reader (MCR). MCR decodes the signal by utilizing soundcard with input from mic or linein. In fact the test could be done synchronously both for reception and decoding. But this need to bring computer outside, so it was decided to record first and decoded it later.

Figure 3-12 Screen Shot of Morse Code Reader

Unfortunately, the callsign could not be decoded clearly, which should be BJ1SA. However, the rest that are after the 13th letter “T” were correct. The telemetry encoding method is specified in its telemetry format[15]. Fortunately, XW-1 telemetry decoding software developed by Mike Rupprecht(DK3MN) could be used for decoding[16]. Just simply copy the decoded message from MCR and paste on the blank, then the software showed Satellite parameters.

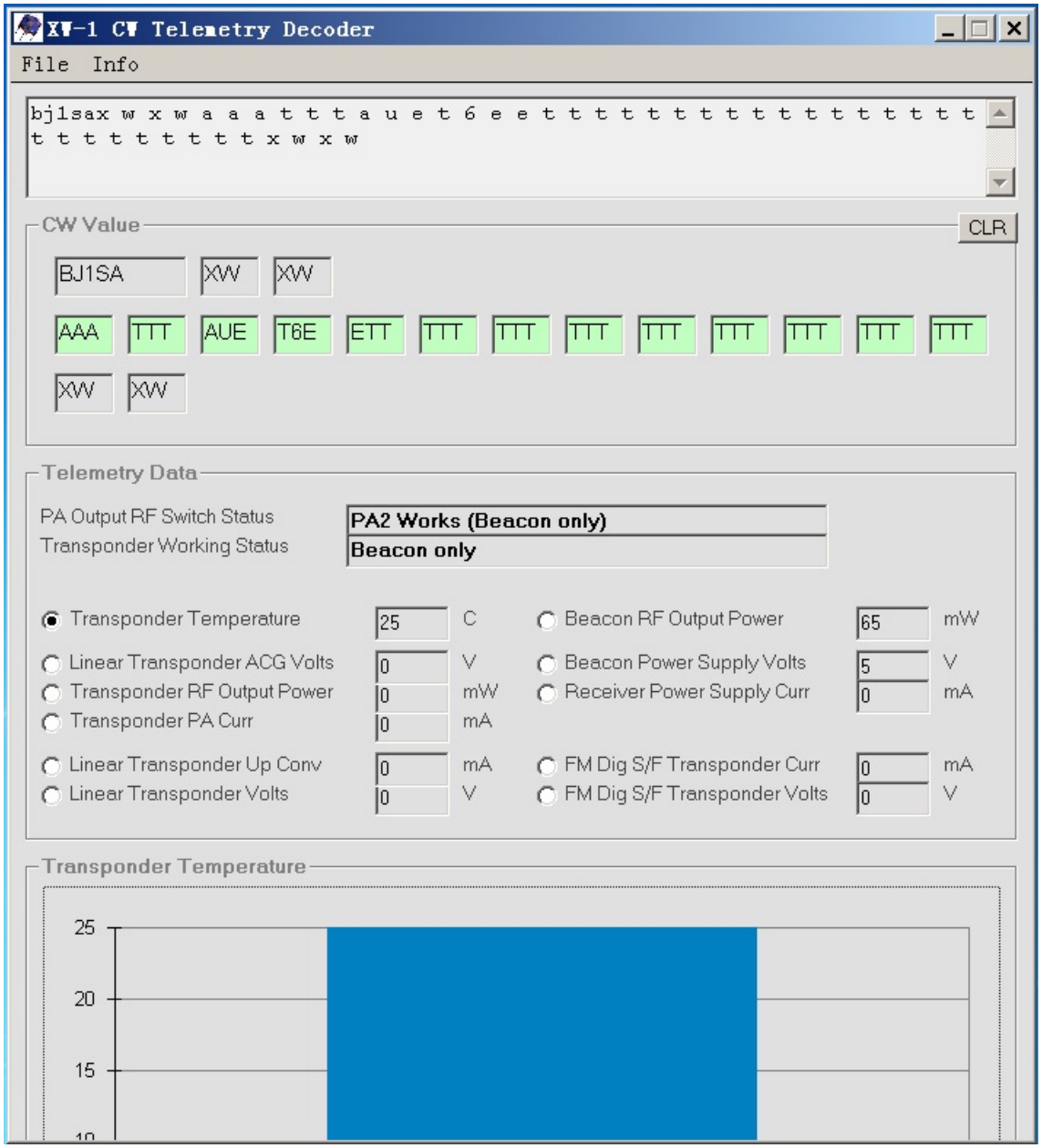


Figure 3-13 XW-1 Telemetry Decoding software [16]

3.3.4.2 AFSK Packet Radio Reception

The telemetry at 145.825MHz from ISS is not the same as the beacon from the CO series cubesats, which should contain the satellite status information. In fact, the amateur radio transceiver on the ISS works as “digipeater”. “digipeater” stands for Digital Repeater which receives digital signal at one frequency and transmits it later at the same frequency. As ISS potentially has a large coverage during pass over, this advantage can be used to forward packet radio in Automatic Position Reporting System (APRS) network. APRS is a real time local information collecting system based on amateur radio communication. Local information which contains weather, location or GPS position from mobile station will be forwarded to neighbour stations through packet radio. Neighbour stations work as “hop” and the packets will be forwarded until they reach a station connected to the internet, which is also referred as IGate. So the packets from some stations under ISS’s coverage could be forwarded to IGate stations which are not directly reachable. And the telemetry from ISS, thus, is the packets from some APRS stations. Anyway, for this test is to receive AFSK packets from ISS at 1200 baud rate, which is also under AX.25 protocol.

Mini system setup was illustrated in Figure 3-7. The TNC was modified to be powered by an internal 9V battery, which can last approximately half an hour. The radio and laptop have already had the internal battery. Hence the whole setup is suitable for outdoor test and doesn’t need any extra power supply.

The packet communication was monitored from AGW Monitor. Its configuration was described in 3.1.4. So once the system is connected, it is ready to receive packet message. This time there was only one target: ISS. And there were a few passages with elevation greater than 80 degrees during one week period. Moreover, the transceiver on the ISS sometimes is off. The chance to get packet signal was rare. However, HRD Satellite Tracking is still used to predict the passages of ISS. The testing place was as same as the last test. Hence the software used the same GPS coordinate.

Actually, before bringing the mini system outside, it was necessary to get familiar with the tone of ASFK signal. One sample was found on the internet:

AFSK 1200 baud.ogg, which was also used for testing by Soyer [10]. This sample can be played in the computer by common audio player. And then a short practice was carried out just with the radio.

On 12th March 2012, the packet signals were heard by the radio and then decoded message was shown on AGW Monitor.

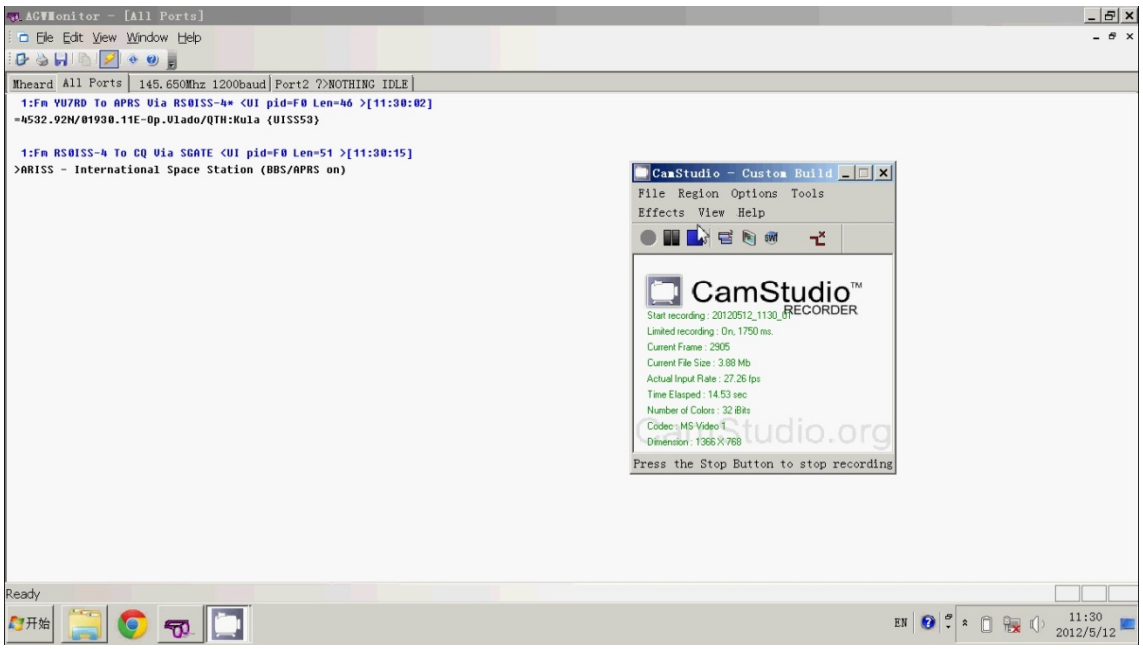

AGWMonitor - [All Ports]
File Edit View Window Help
Mheard All Ports 145.650Mhz 1200baud Port2 ?>NOTHING IDLE
1:Fm YU7RD To APRS Via RS0ISS-4* <UI pid=F0 Len=46 >[11:30:02]
=4532.92N/01930.11E-Op.Vlado/QTH:Kula {UIS53}
1:Fm RS0ISS-4 To CQ Via SGATE <UI pid=F0 Len=51 >[11:30:15]
>ARISS - International Space Station (BBS/APRS on)
CamStudio - Custom Build
File Region Options Tools
Effects View Help
CamStudio™ RECORDER
Start recording : 20120512_1130_0
Limited recording : On, 1750 ms.
Current Frame : 2905
Current File Size : 3.88 Mb
Actual Input Rate : 27.26 fps
Time Elasped : 14.53 sec
Number of Colors : 32 iBits
Codec : MS Video 1
Dimension : 1366 X 768
Press the Stop Button to stop recording
Ready
开始
EN
11:30
2012/5/12

Figure 3-14 AFSK Packets heard from ISS shown in AGW Monitor

3.4 Conclusion

In this stage, the study of hardware and software was first carried out. And then hardware connection and software configuration was performed properly. Hence, every device was learnt to be functioning within the system.

An introduction about amateur radio communication frequency, modulation method and protocol was described. This enhanced the comprehension of amateur radio operation and the application in Cubesat communication.

Two types of small systems were constructed for the outdoor testing. TNC was modified to be suitable for outdoor use. HO-68 and ISS were selected based on the criterion of high signal reception possibility. Before the preliminary test, link analysis was done for each type test. And then some practice was carried out to

get familiar with radio operation and signal recognition. Finally, the tests were implemented first with CW then followed by AFSK packet radio. Both tests were successfully done and met the goal.

4 GROUND STATION FINALISATION

In this chapter will first review the drivers and requirements for the GS. And then the detailed hardware and software is described. After that the problem of remote control of the equipment powers is introduced, then follows the progress of the solutions, finally the control principle, construction and implementation of the webserver controller is depicted. At the end, the system architecture is finalised.

4.1 System Requirements

GS is the essential segment that enables communication with spacecraft. It provides an interface in not only remote control of spacecraft but also retrieving payload data for further analysis. A typical Cubesat GS comprises amateur radio transceiver, Yagi antennae with rotator controller, TNC, power supply and computer with miscellaneous control and data processing software. The GS should be placed in a dedicated room with stable power supply, where is far from RF interference and other disturbances. Moreover, the control room should be close to antennae to avoid the feed line loss. And the antenna will be placed at where there is good field of view, which means there are no other buildings and obstacles in sight of the antenna, and the antenna is able to see most of satellites where they are in 10° elevation above the horizon. The summarized key requirements are listed as follows:

- Amateur radio transceiver with VHF/UHF band at least, possibly duplex working mode.
- CW, FM, SSB and AFSK modulation method
- Automatic antennae directing system
- Automatic Doppler Shift control
- Antennae location has good field of view and close to the control room
- Dedicated control room with stable power and minimum RF interference
- Easy to access and maintenance,
- Able to be shut down immediately when necessary
- Possibility of remote control

- Lightning protection and well grounded
- Compatible with GENSO network

All above requirements were the initial drivers when doing the design. Based on these consideration Long first investigated the fundamental hardware and software that should be used for the GS. Some main devices were purchased. The continuous project study eventually completed the whole system.

4.2 GS Hardware

The GS was designed and constructed by following the requirements. During first project study, the core devices were bought, such as amateur radio, rotator with controller and amplifiers. Rotator control interface and lightning protection system were purchased during second study. And during third project, antenna, TNC and other miscellaneous components were ordered and received. At present, one enclosure for ERC-3D was bought. Polarisation switches, SWR meter and material for antenna support are to be ordered. Thus, the GS is gradually perfect. The main hardware of the GS is briefed as follows:

Transceiver: ICOM 910H is a multimode amateur radio with a special feature designed for satellite operation in VHF/UHF band. Another important feature is computer controllable which enables the remote control capability.

TNC: KPC-3+ is a single port terminal node controller for packet radio modulation and demodulation at a data rate up to 1200 baud. It is the essential device when the GS links to Cubesat for data communication in AFSK mode.

Amplifier: AG-25 & AG-35 are the low noise preamplifiers that improve the SNR and receiving sensitivity. They are waterproof designed for outdoor use in VHF and UHF band respectively. They come along with ICOM 910H radio as the unique accessories which should be enabled from the radio control. Between amplifier and the radio, it is suggested not to connect any other devices.

Antenna: X-Quad 2M and 70cm band antennas are design by WIMO, which are suitable for amateur radio application with higher gain in a compact size. 2M

antenna has 10.5dB gain with 12 elements while 70cm antenna has 12.8dB gain with 18 elements. The polarisation is switchable by a coax relay or a remote control polarisation switch.[17]

Rotator Controller: Yaesu G5500 rotator controller is a heavy duty, all weather antennae directing device, providing with turning range of 450° in azimuth and 180° in elevation.

Rotator Controller interface: the ERC-3D is an invention providing an interface between rotator controller and the computer, through which the antenna directing could be controlled by the computer.

Polarisation Switch: it was invented by Wimo, which is compatible with X-Quad antennas. The idea is to use coax cable with different length and impedance to relay the signal between horizontal and vertical elements. The remote control version is more convenient as it reduces the access to antenna area.

Power Unit and IP switch: As the radio has special power voltage 13.8V, a dedicated power unit was bought for it. In addition, in order to fully remote control the GS an IP controlled switch was purchased.

Lightning Protection: it is very important to protect the GS from lightning. All the connections from antenna will be guarded before going inside building.

Above devices have been ordered and received, except Polarisation Switches which are on order. Some components may be reordered as they were not found in the lab.

4.3 GS Software

Software plays an important role in the satellite operation, even more than hardware does. Typically, they are costly since being bespoke and unique developed to the specific mission. In contrast, software used for Cubesat operation is mostly developed by amateur radio enthusiasts. Thus they are very low cost and simple but multifunctioning which could fulfil the needs of Cubesat

operation. However, Cubesat control software has to be bespoke hence unique to the mission.

Cubesat operation requires the GS able to track with high accuracy antenna pointing and data communication. Thus the GS software must be of the function of helping operation, management and data processing. To be more specific, the software must be able to control tracking and directing antenna, the RF equipment and manage data processing work.

4.3.1 Operation and Control

As mentioned earlier, HRD is the main software in the GS operation, involving radio control, satellite tracking and rotator control. All these functions ensure the data communication. Data processing software used in the GS are AGW series, currently AGWPE and AGW Monitor for packet radio operation. CWget can be used for decoding CW beacon. In order to control Cranfield's own Cubesat in future, the control software has to be bespoke according to the mission. Software listed below follows the general GS operation sequence.

HRD Satellite Tracking is used to predict the next passages and schedule the operation. The satellites tracked in the software are represented by TLE which can be updated from AMASAT and CELESTRAK's database. The passages can be displayed in Elevation, Radar and World Map format with real time orbital parameters, such as, AOS, LOS, Altitude and Range. Furthermore, it provides the data to HRD rotator.

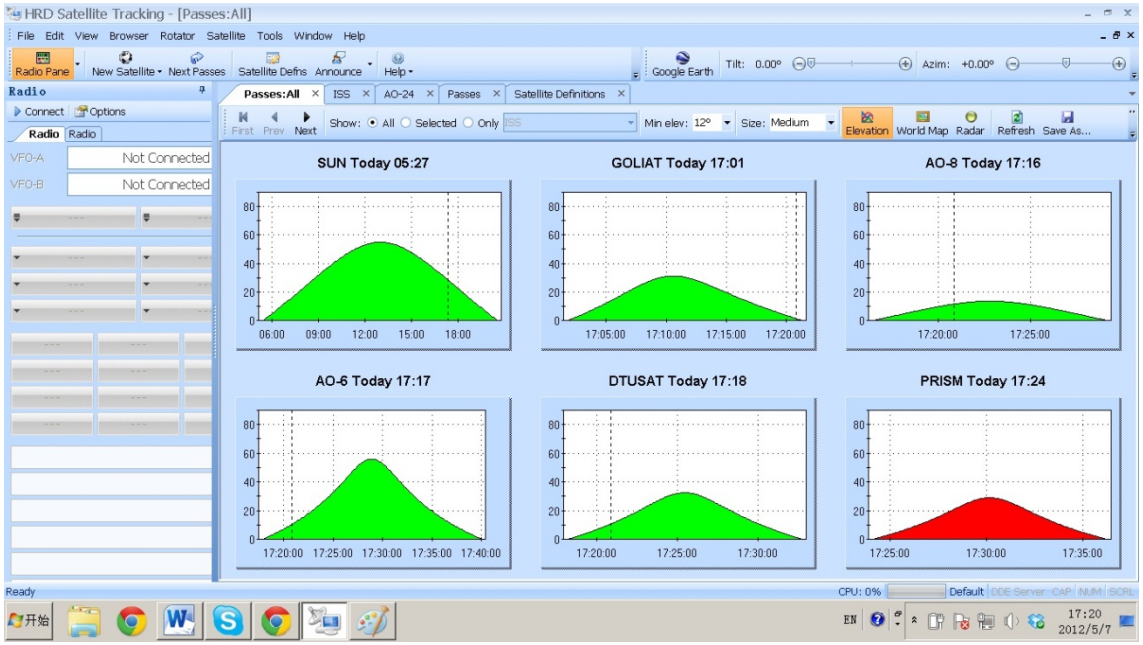


Figure 4-1 HRD Satellite Tracking Screenshot

HRD Radio Control provides a duplicated control panel of the transceiver which must support CAT. Through the interface provided by this software, user can control the frequency, mode, transmitting power and some other parameters of the transceiver. See Figure 3-1 in 3.1.1.1.

HRD Rotator unitizes the data from HRD's DDE server and drives the rotator control through ERC-3D interface, hence directing the antennas towards the target. This function is fully automatic once enabled.

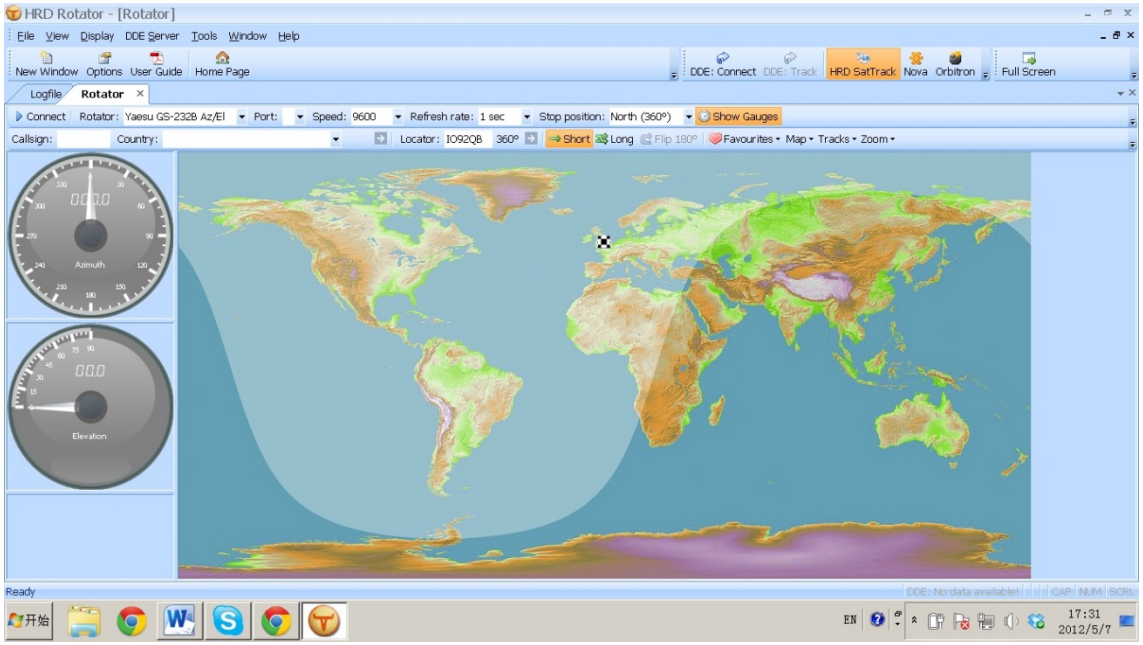

HRD Rotator - [Rotator]
File View Display DDE Server Tools Window Help
New Window Options User Guide Home Page
DDE: Connect DDE: Track HRD SatTrack Nova Orbitron Full Screen
Logfile Rotator
Connect Rotator: Yaesu GS-232B Az/El Port: Speed: 9600 Refresh rate: 1 sec Stop position: North (360°) Show Gauges
Callsign: Country: Locator: IO92QB 360° Short Long Flip 180° Favourites Map Tracks Zoom
Azimuth
Elevation
Ready
DDE: No data available!
CAP NUM SCRL
开始
EN
17:31
2012/5/7

Figure 4-2 HRD Rotator Control

AGW Packet Engine is a small program compatible with KPC3+ in XKISS mode. This program bridges the TNC and AGW Monitor or Terminal. It demodulates the signal and sends to AGW Monitor or modulates the message and sends to TNC. A new version program is available, which is called Packet Engine Pro, it connects to TNC directly and displays the demodulated message[18].

AGW Monitor displays the messages from all the ports it heard, including Soundcard input. See Figure 3-14in 3.3.4.2.

Bespoke Cubesat Control Software has to be developed for monitoring and controlling the Cubesat. It should be compatible with TNC in order to demodulate the telemetry from Cubesat and modulate the telecommand to transceiver. Telemetry should be analysed in real time with the assessment of the power, attitude, bus voltage, the status of payload and other parameters of the Cubesat. Telecommand in the software should be represented by graphical or text items which are linked to the preprogramed and on-board controller executable codes. It has to be received by Cubesat with acknowledgement back to the GS.

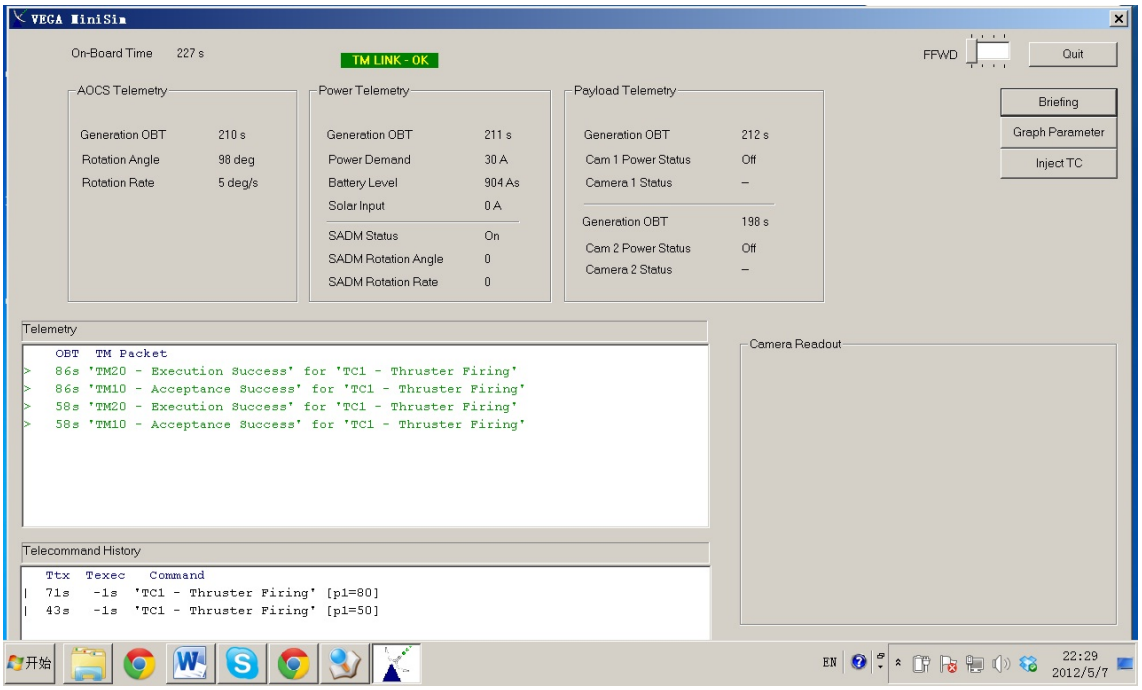


Figure 4-3 MiniSim Spacecraft Control Software Simulator

4.3.2 Remote Control

The GS will be located in the corridor of third floor of the B52 as the closest place to the antenna site just above. However, the building belongs to the School of Health, and the access to the corridor was agreed but not convenient. Thus, remote control of the GS was required. Previous study has pointed out to use commercial network desktop control software as the solution. After testing several existing desktop control software, Splashtopwas selected[19].

Operation Control

The test was to play a HD movie on desktop and watched on remote control, while Splashtop has minimum delay which can meet the requirement. Moreover, another nice feature is that it disables the sound on desktop automatically and forwards to the remote control terminal. It is compatible with various operating systems, even apps for Apple OS, Android.

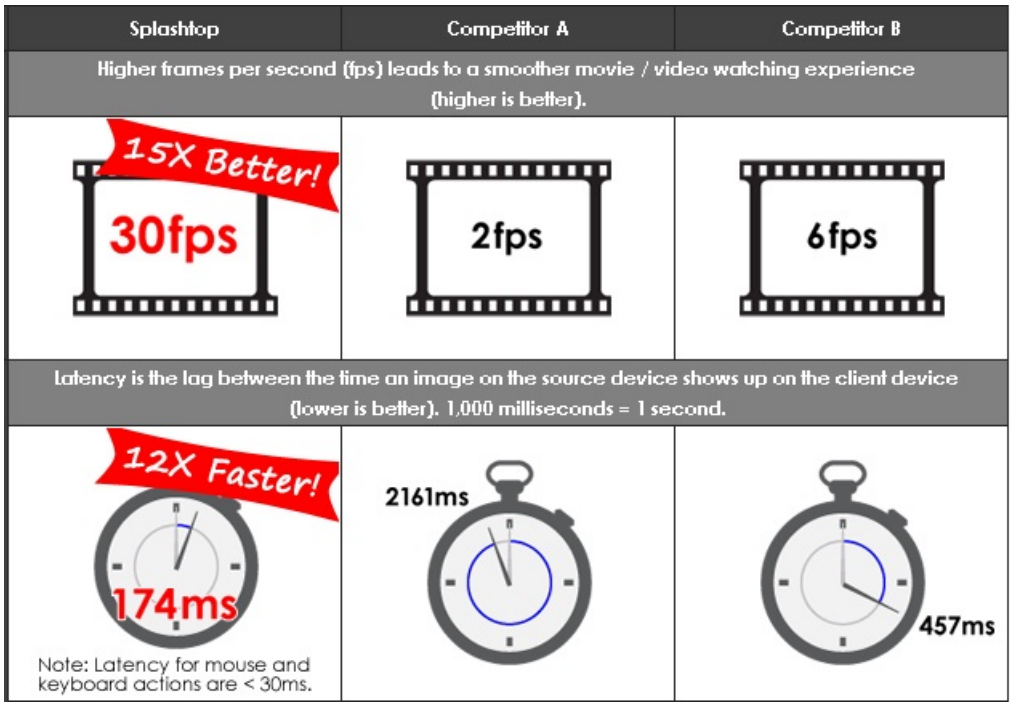

Splashtop
Competitor A
Competitor B
Higher frames per second (fps) leads to a smoother movie / video watching experience (higher is better).
15X Better!
30fps
2fps
6fps
Latency is the lag between the time an image on the source device shows up on the client device (lower is better). 1,000 milliseconds = 1 second.
12X Faster!
174ms
Note: Latency for mouse and keyboard actions are < 30ms.
2161ms
457ms

Figure 4-4 Splashtop Compared with the Others [19]

Power Control

Although radio can be operated through Splashtop, it is not applicable to control power on/off of ICOM 910H as manufacturer doesn't release this function. However, effort has been tried, such as sending command to radio by Command Tester. It is the same principle as CAT to control the radio. The Command Tester generates the codes and sends it to radio controller through the CI-V cable. The address of the controller of ICOM 910H is 60, E0 is for computer, 18 is the main command, 00 is the sub command for power off and 01 is the sub command for power on. The command frame is as:

$FE	$FE	$60	$E0	$18	$00	$FD

Table 4-1ICOM 910H CAT Command Frame

FE is the standard header and FD is for ending. Unfortunately, this trial didn't succeed as the command may not be supported. Further trial was not carried out as there is risk of damaging of the radio controller.

4.4 Webserver Power Controller

One objective of this project is to enable the remote control of the GS due to the inconvenience of accessing of the corridor where the GS is located. Furthermore, fully automated GS is also required in order to join GENSO network. The previously mentioned control software is not doubted for operation. However, some devices are not able to be powered on through software control. Thus a way to control the power on those devices has to be developed. For example, the power button of ICOM 910H has to be physically pushed in order to start or shut down. For controlling the polarisation switches, suggested method is to use a single axis 4-way rotary switch which is not provided. Nevertheless it is suitable for manual operation. Hence bespoke dedicated control software could be developed for the application. However, this requires advanced knowledge in software engineering and increases the difficulties.

The operation of remote control is implemented through the other computers in campus, or somewhere within the GENSO network. Therefore the connection link must be by means of internet, which is the most common way to access control remotely. Nowadays, IP switch is a quite widely used method for power control remotely. In fact, it is suggested to use IP switch by last project study and it has been purchased. But the problem is that it has only 4 power outlet in IEC320 standard. To be suitable for the GS, IEC320 to UK standard power socket adapter is required. Ideally, the power of control computer, radio power supply, radio, TNC, rotator power and ERC-3D need to be controllable. It is still far from the requirement of the application. Even polarisation switches need 6 switches.

4.4.1 Arduino Duemilanove + Ethernet Shield

Although the IP Switch cannot be used in the application, it gives a bright idea of control. Actually, IP Switch works as a webserver with microcontroller controlling the relays. There are many examples that using microcontroller to build webserver hence to control other devices through internet remotely. The most popular and easy one is to use Arduino Duemilanove with its Ethernet Shield.[20] Duemilanove employs an ATMEG328 microchip and has 14 digital

I/O pins, 6 analogue pins which can also be used as digital pins. While in this project pin 10-13 are reserved for Ethernet Shield, they can not be used in any other program. Ethernet Shield is based on Winznet W5100 Ethernet chip, allowing Arduino board to connect to internet in mere minutes. It can be simply stacked on the board and all the connections made.

4.4.2 Web Server Pin Assignment and Wiring

Pin layout of the Ethernet Shield is the extension of Duemilanove, so connections can be wired directly from the shield. Pin10-13 and 1-2 are occupied and can not be used. Each polarisation switch has three power connections plus common ground, as it switches to Vertical when no voltage applied. Pin 8 and 14-19 are assigned to control the power of the devices. To control the servo, it requires Pulse Width Modulation (PWM) signal. On Duemilanove board pin 3, 5, 6, 9 and 11 have the PWM capability and pin 9 was selected for the application.

Arduino Duemilanove Pins Assignment	
Pin No.	**Assignment**
2	VHF Horizontal
3	VHF RHCP
4	VHF LHCP
5	UHF Horizontal
6	UHF RHCP
7	UHF LHCP
8	Power Switch 1
9	Servo
14(A0)	Power Switch 2
15(A1)	Power Switch 3
16(A2)	Power Switch 4
17(A3)	Power Switch 5
18(A4)	Power Switch 6
19(A5)	Power Switch 7

Table 4-2 Web Server Pins Assignment

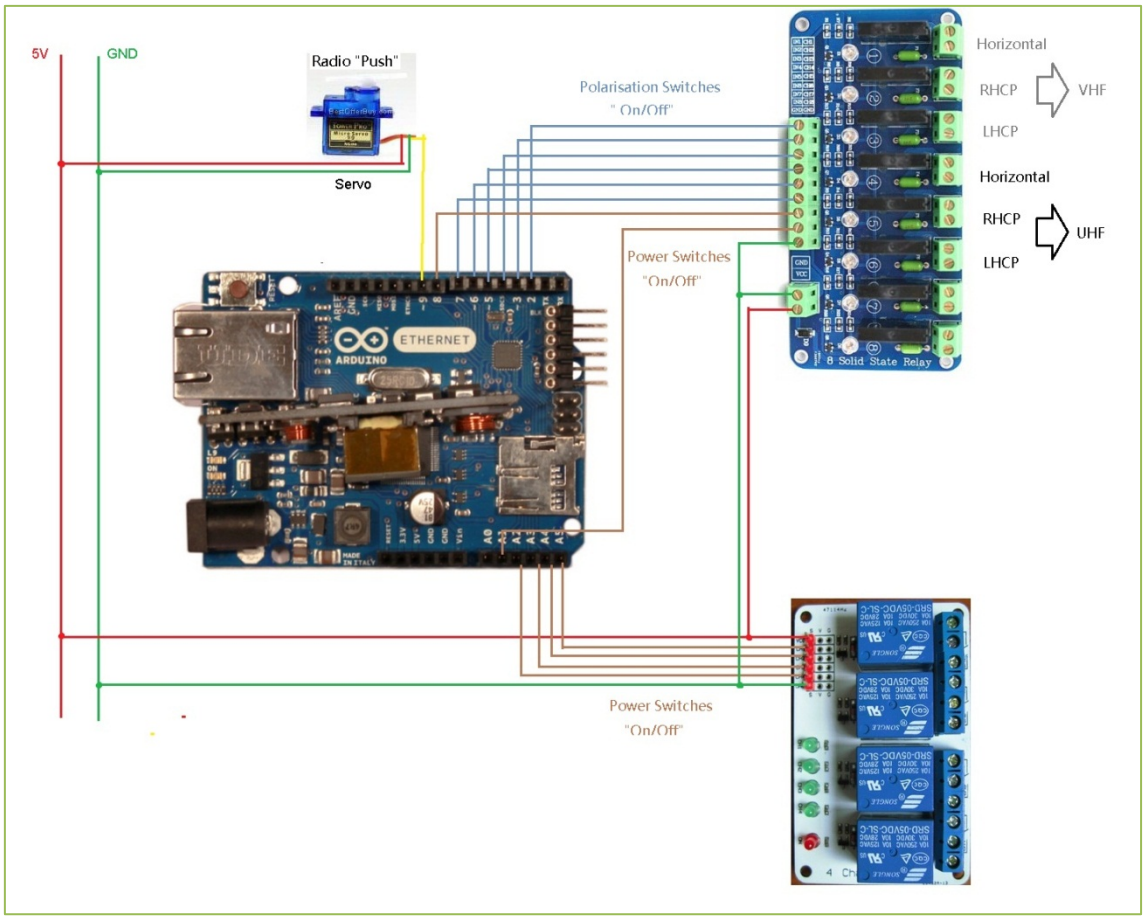


Figure 4-5 Web Server Controller Wiring Method

This program was gradually developed. At the beginning, only polarisation switches function was studied and then the servo control. Fortunately, the study was successful and both functions were enabled. Now all the devices are controllable except theirs power. Thanks to the idea from IP Power Switch, this function can be easily implemented in the program as they are same principle. Therefore, the program was expanded to have 12 switches which are 6 polarisation switches and 6 power switches. However, due to the memory limit of the Duemilanove, the program could run but the webpage can not be loaded successfully. The trial shows that only two power switches can be implemented. At the moment, there are 6 power plugs. It is better to control them separately, because there is electric disturbance which could affect the other devices when turning on or off the power supply of the radio. Moreover, the plan was to also embed the IP camera stream into webpage, thus a board with bigger memory was needed.

Finally Mega2560 could fulfil the requirement. It is compatible with the Ethernet Shield with 54 I/O pins and 16 analog input pins. It has 256 Kb flash memories (Duemilanove 32Kb).[21] This will be good for later development.

Arduino Mega2560 Pins Assignment	
Pin No.	**Assignment**
2	VHF Horizontal
3	VHF RHCP
4	VHF LHCP
5	UHF Horizontal
6	UHF RHCP
7	UHF LHCP
9	Servo
22	Power Switch 1
24	Power Switch 2
26	Power Switch 3
28	Power Switch 4
30	Power Switch 5
32	Power Switch 6

Table 4-3 Arduino Mega2560 Pins Assignment

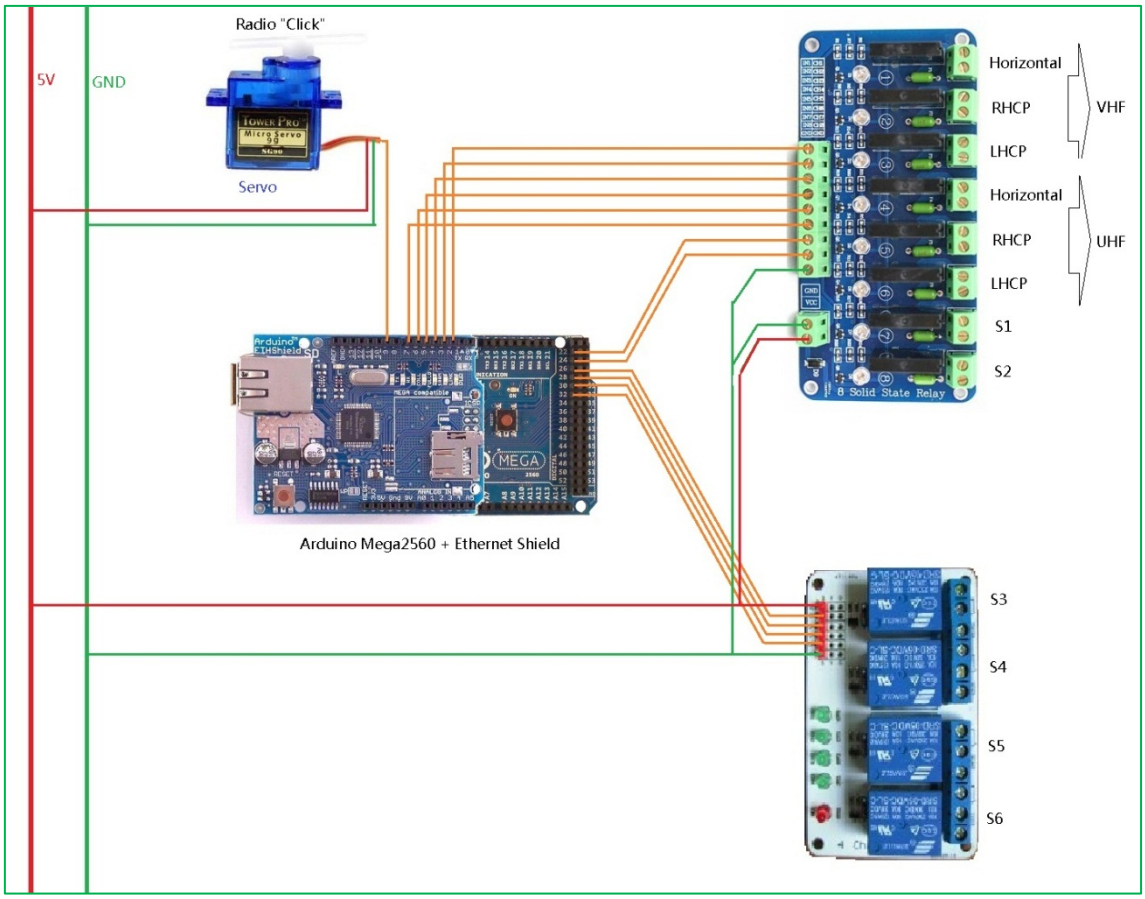


Figure 4-6 Arduino Mega2560 Wiring

4.4.3 Power on Computer Remotely

Computer is the last equipment to be considered for the power control remotely. Same as the radio, once it is switched off the start button has to be pressed to start. There are several methods can remotely power on the control computer.

Wake-on-LAN is the common way to power on computer through internet. First the network card should have this function and the function should be enabled. Second the BIOS must also have this function. A command is called “Magic Packet” can be sent to power on the computer from anywhere through internet. “Magic Packet” contains MAC of the destination computer and IP address. However, this requires the power unit of the computer to be on all the time to provide power to motherboard and network card. An IT specialist suggested that in current Ethernet this may not be applicable, because of different network in B52 and B52A.

Another method is to modify the Start button of the computer. Normally it is a touch button with two wires. It connects two wires in a short time when the button is pressed. This could be feasible by a relay with microcontroller. The disadvantage is the two wires need to be led out of the computer case and the power unit has to be on also.

The last method which is used is to enable a special feature in BIOS of the control computer. Then just control the computer with Mega2560 Power Switches. The special feature is Restore on AC Power Loss. Once it is enabled, the computer will automatically start when there is power.

Figure 4-7 Enable Restore on AC Power Loss in BIOS

The operation principle is to use Power Switch to turn power off during lightning or to save power, and turn power on when there is an operation needed.

4.4.4 Control Principle

When the programed Webserver connected to the internet, an IP address will be assigned to it. Then the webserver can be accessed remotely from anywhere by typing the IP address into a web browser, such as Google Chrome, or Mozilla Firefox. In the current Ethernet where the Dynamic Host Configuration Protocol (DHCP) is applied, every device has to be configured before it can communicate with the other hosts. The new version Ethernet library of Arduino can configure IP address automatically which makes the programming fairly easy.

```
#include <Ethernet.h>

  byte mac[] = { 0xDE, 0xAD, 0xBE, 0xEF, 0xFE, 0x01 }; // mac address

  EthernetServer server = EthernetServer(80); //port 80
```

```
void setup(){
  Ethernet.begin(mac);
  server.begin();
}
```

Once the Webserver is connected to the internet, it then prints out the IP address in the Serial Monitor which can be found from IDE's Tools. Filling the IP address into IE browser, the control interface will show up. The control interface is written in html format. When clicking the control buttons, the corresponding string command will be generated. String command is understood in data format by Duemilanove.

The control string command of servo hence the radio is defined as name = "radio" and value = "5". Command will be sent to microcontroller when the button is clicked. Then microcontroller will compare the value and tell servo whether to execute the designed action. If the string value > 0 meaning the control button is clicked, then the servo will move to 140˚, otherwise will keep at 80˚ with 800milisecond delay.

```
if (inString.indexOf("radio")>0 ){
        radio.write(140);
        delay(800);
        Serial.println("radio on");
      }else{
        radio.write(80);
      }
```

The control of switches is easier than controlling a servo. Each switch has a unique name with initial value "off". When the control button is clicked, then the command string will be sent to the microcontroller. Whereafter the microcontroller compare the string data plus value with zero. If bigger than zero

then put output pin to “HIGH” and display value “off” or “on”, otherwise put output pin in “LOW” and value in “on” or “off”.

```
if(inString.indexOf(Vhf2+"=on")>0 ){
        Serial.println(Vhf2+"on");
        value2 = "off";
      }else if(inString.indexOf(Vhf2+"=off")>0  ){
        Serial.println(Vhf2+"off");
        digitalWrite(VHF2, LOW);
        value2 = "on";
      }
client.println("<br><input type=submit name="+Vhf2+" value="+value2+">Horizontal");
```

where Vhf2 is the predefined string, VHF2 is attached to digital pin, client.pintln is the command to print result in webpage which is written in html format.

4.5 System Architecture

The whole system structure comprises indoor and outdoor sections. The preamplifiers, polarisation switches and antennas with its pointing system are seated on the mast on the roof of B52, while the rest of the devices and equipment are placed in a cabinet at the corridor of the third floor. The link between outdoor and indoor segments is the coax and power cable. There will be junction box before cables go inside the building for lighting arrestors and surges. The GS will be connected to the internet.

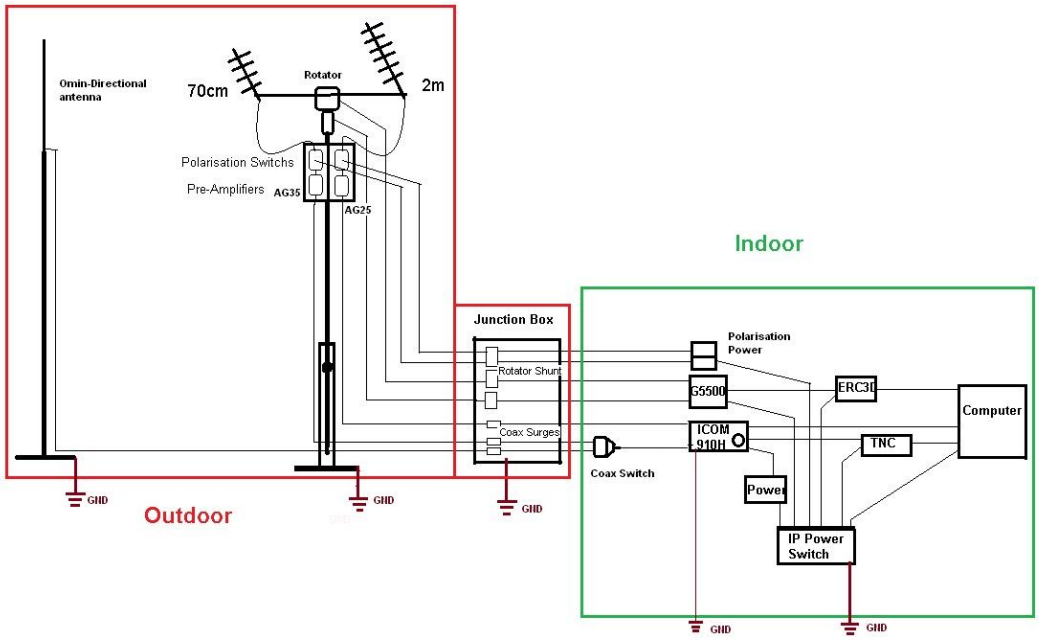


Figure 4-8 Ground Station Structure

Name	Item	Specification
Ground Station	Call Sign	CRANSAT
Location		Cranfield
	Longitude	0°37.89'
	Latitude	52°4.50'
	Altitude	133m
VHF Antenna	Gain	10.5dB
	Beamwidth	46°Horizontal 47°Vertical
UHF Antenna	Gain	12.8dB
	Beamwidth	36°Horizontal 36°Vertical
Omni-Directional Antenna	Moonracker	SQBM110P MkII BAND 2/70 VERTICAL
VHF pre-amplifier	ICOM	AG-25
	Gain	15dB
UHF pre-amplifier	ICOM	AG-35
	Gain	15dB
Polarisation Switch	Wimo	VHF 18080
	Wimo	UHF 18082
Rotator Controller	Yaesu	G5500
	Computer Interface	ERC-3D
Terminal Node Controller	Kantronics	KPC3+
Radio	ICOM	910H
Power Supply	Rapid Electronics	PS1540S
Mast	Galvanised Tube	6m 3" Tube + 3m 2" Tube
Lightning Protection	Rotor Shunt	PolyPhaser Lightning Protector
	AC Power Surge	Maplin
	Ethernet Surge	RJ45 Surge
	Coax Surge	DIAMOND SP-1000
Webserver Controller	Arduino	Mega2560
	Arduino	Ethernet Shield
	Extension Lead	8-Way Surge Protected Extension
	MiniServo	9G Servo
	Relay Module	4-channel Relay Module
	SainSmart	8-channel Solid State Relay Module
SWR & Power meter	AVAIR	AV-1000
PC	Hardware	CPU E8400 3GB RAM
	Operation System	Windows XP
Software	Pre-Pass	HRD Satellite Tracking
	Real Time	HRD Radio Control HRD Rotator AGW Packet Engine AGW Monitor AGW Terminal CWget
Desktop Remote Control		Splashtop

Table 4-4 Cranfield Ground Station Specification

5 ANTENNA MAST SUPPORT DESIGN

In this chapter, a new function requirement for the antenna mast support will be introduced at the beginning. And then the preliminary design will be exhibited. After that the antenna wind load analysis will be described, with referring to the Kawak's analysis. Finally, an improved design will be explained focusing on some designed features which meet the implied requirements.

5.1 New function requirement

When taking over this project, one of the major tasks is to design a mast support mechanism with pivoting function. The main purpose of it is for easy maintenance of the antennas on top of the mast. In other words, it doesn't have to be sliding down vertically instead of tilting down. This feature will help not only maintenance but also installation. The rotator and antenna on the top is close to 20Kg, creating 1177Nm moment to the pivot join when lifting up the antennas initially.

The antenna mast support will be placed on the roof of B52A. The roof comprises two types: concrete and steel structure. As the surface of concrete is the water resistant layer, it is not allowed to attach anything on it. Steel structural roof is the only place to attach the antenna support. Due to the special circumstance, antenna mast will only tilt toward the concrete roof. As there is a 1.2m hand rail between them, the pivoting point has to be 1.2m high at least.

The system will last at least for 10 years, thus anti-corrosion has to be considered for the material selection. Moreover, the material should have high strength to resist the high moment created by strong wind in worst case.

5.2 Previous design and wind load analysis

During previous project study, the antenna mast support is just a 23cm x 23cm square aluminium plate which has been purchased. It is supposed to be fixed on the steel grid floor with 4 steel bolts at a grade of 10.9. Then the 4 segments antenna mast will be attached on it. The mast will be stabilized with 6 Kevlar guy ropes at 2 different heights, 3 guy ropes with 120° separation at each height.

The guy ropes will be anchored to the hand rail around the roof floor. Angles between guy ropes and antenna mast are 24.5° for top three and 42.5° for lower three. Kawak's calculation shows this configuration can resist 160Km wind with a safety factor of 2.78.

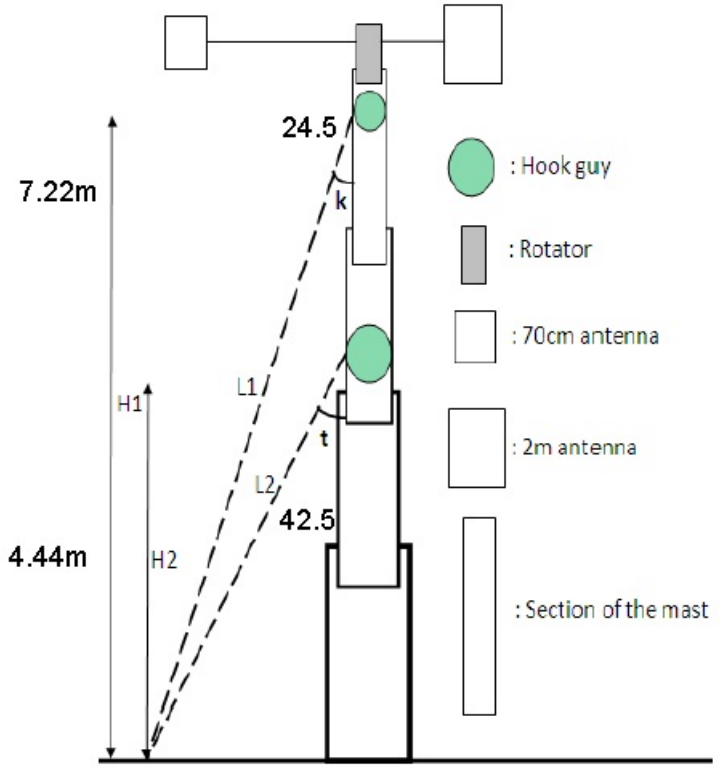


Figure 5-1 Kawak's design (*Extracted from his thesis*)

After the project review, it was realised that although the above design is able to resist 160Km wind with a certain safety factor, it is suitable for mobile and temporary usage. Moreover, the fixing method of the base plate has to be redesigned as it has to be attached to the main beam of the floor rather than the steel grid floor. And the guy rope anchor method has also to be reconsidered.

5.3 Improvement

Considering for later easy maintenance and installation, a new design is required for the antenna mast support. Several points should be kept in mind during the design:

- ✓ No harm to the roof structure

- ✓ Easy for installation and calibration in order to achieve the pointing accuracy
- ✓ Easy for maintenance, including a pivot function
- ✓ Anti-corrosion and good conductivity

Pivoting function is the primary requirement to be considered when taking over the project. The mounting position of the antenna support is on the steel grid floor, and the pivoting point should be 1.25m above the floor because of the height of hand rail.

5.3.1 Preliminary design

At the beginning two preliminary solutions were designed to enable this requirement: hand winch and count-weight.

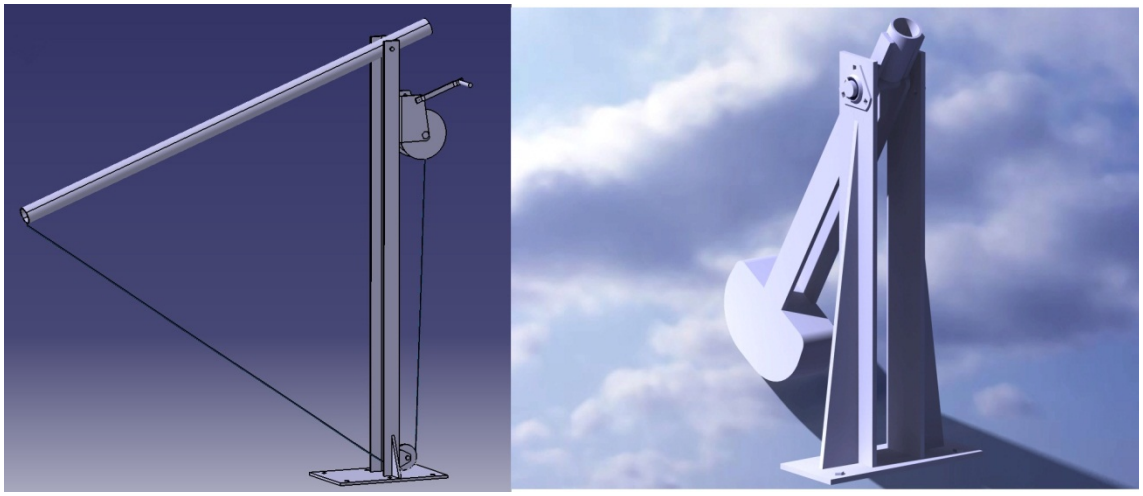


Figure 5-2 a) Hand winch solution b) count weight solution

The two preliminary designs have been modelled in Catia for visualization. The detailed dimension will be added after the site survey measurement, and also according to the available structural material.

5.3.1.1 Counter weight design

Two Flange Triangle Housing bearings are used to support the pivot shaft. This pivot shaft is not only used to withstand the counter weight, the antenna and the mast, but also need to be placed horizontally with high precision. As it will affect

the accuracy of elevation, high precision is required for the installation of two bearing housing.

Count weight at the bottom of the antenna mast is a flat block which should be kept as far as possible from the pivoting point, and it is thin to reduce the length of pivoting pin. Thus there is only one dimension can be adjusted to increase the volume hence the weight. An optimised weight was designed to be 70Kg whose centre gravity is 0.75m away from the pivoting point. This can give 515Nm moment. However, it need to be attached to the mast with high accuracy, otherwise any offset could create high torque on the mast when it is in horizontal position. Though heavy block could low down the centre gravity of the structure hence increase the stability. Comparing to the load 1177Nm, this gives a little gain while increasing the difficulty of installation as the heavy block has to be lifted to the roof.

5.3.1.2 Hand winch design

The aim of this design is minimize the manpower needed for installation and maintenance. It is lighter and simpler than previous one with the help of a hand-operated winch. Its main structure is a flat base plate with a vertical steel channel. And winch is attached behind the channel by bolts. Winch cable is hooked to the end of mast through a slot at the bottom of the channel. The pivoting pin will be placed horizontally through two limbs of the channel. Its distance to the parallel wall is determined by the outer radius of the first bottom mast, in this case, is 25.4mm. And the mast will be clamped against the wall hence it will be vertical to floor.

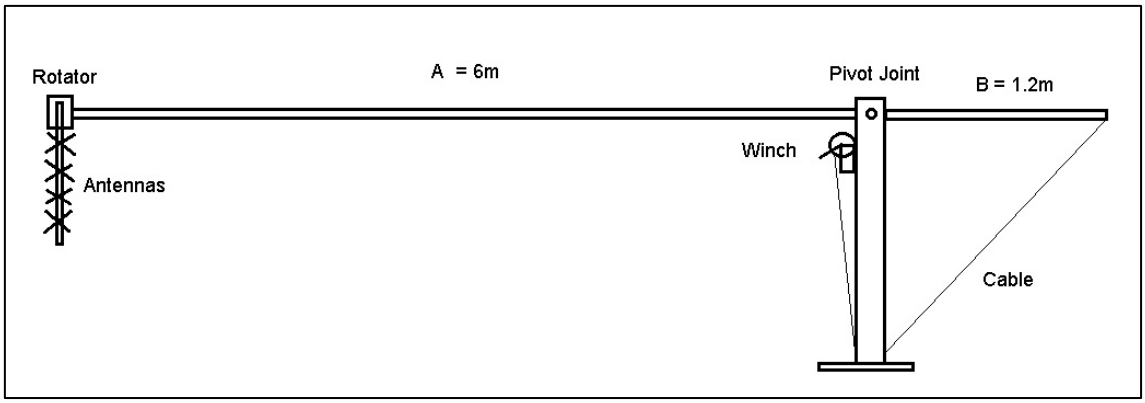


Figure 5-3 Winch Design Illustration

The pulling force can be calculated by:

$$\mathrm{MgA} + \mathrm{FxB}\sin 45 = 0 \qquad \textbf{(5-1)}$$

where M is the mass of antennas and rotator and mast, g is the gravitational constant, A is the length of the mast from top to pivoting joint, F is the initial pulling force and B is the length from bottom to the pivoting joint. The relationship is illustrated in Figure 5-3 above.

Thus the pulling force on the winch cable is 1387N. This is the minimum pulling capability required when selecting a hand operated winch. After a comparison by price, Yale Worm Gear winch with 250Kg pulling capacity is selected for this application.

As the horizontal position has maximum moment, it is necessary to check whether the material strength is sufficient to support this load. The whole structure was modelled in Catia and analysed by its Generative Structural Analysis (GSA) module. Finite element method was applied in this module to analyse the structure, and a mesh was created to represent the geometrical and physical properties. Although the accuracy is determined by the mesh size, the finer the mesh size is, the more accurate result it will be. However, the fine size needs more computer power for calculations. As a result, the mesh size was determined by the geometry of each element. The analysis shows that the aluminium mast is not able to lift the load, as the maximum required strength

300MPa is far beyond its strength limit. Figure 5-4 below shows the analysis result of the antenna mast.

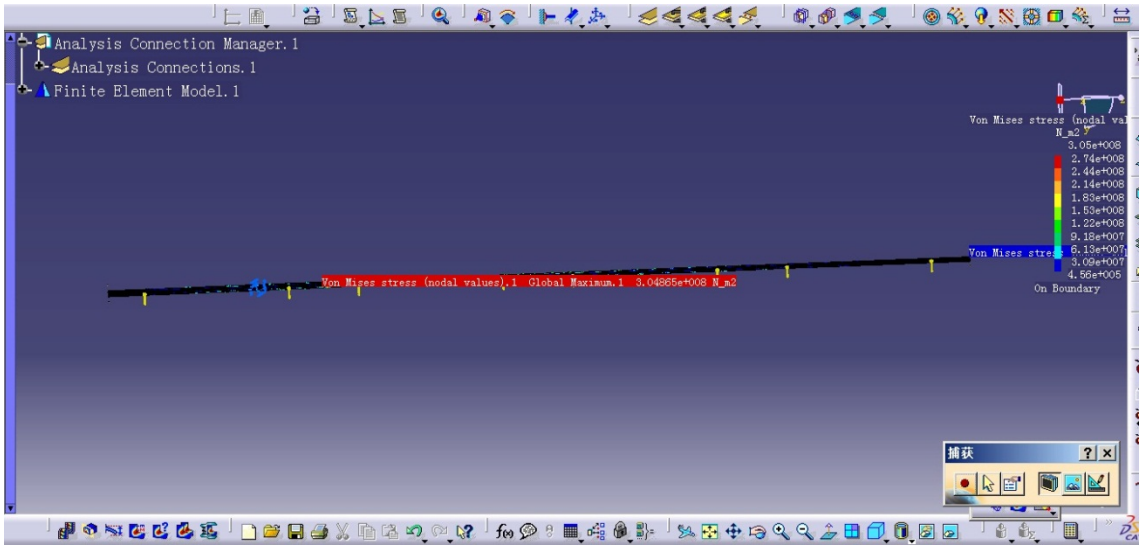


Figure 5-4 Antenna mast finite element analysis

The result indicates two main aspects that have to be improved: mast pivoting joint and hooking method of the winch cable. In above design, the pivoting pin through the mast will weaken the strength. Hence the pin should be reinforced with a holder for the mast. The long mast should be enhanced in order to lift the load. After a discussion with a technician Mr.Derek Brown, an improved design was proposed to fulfil the requirement.

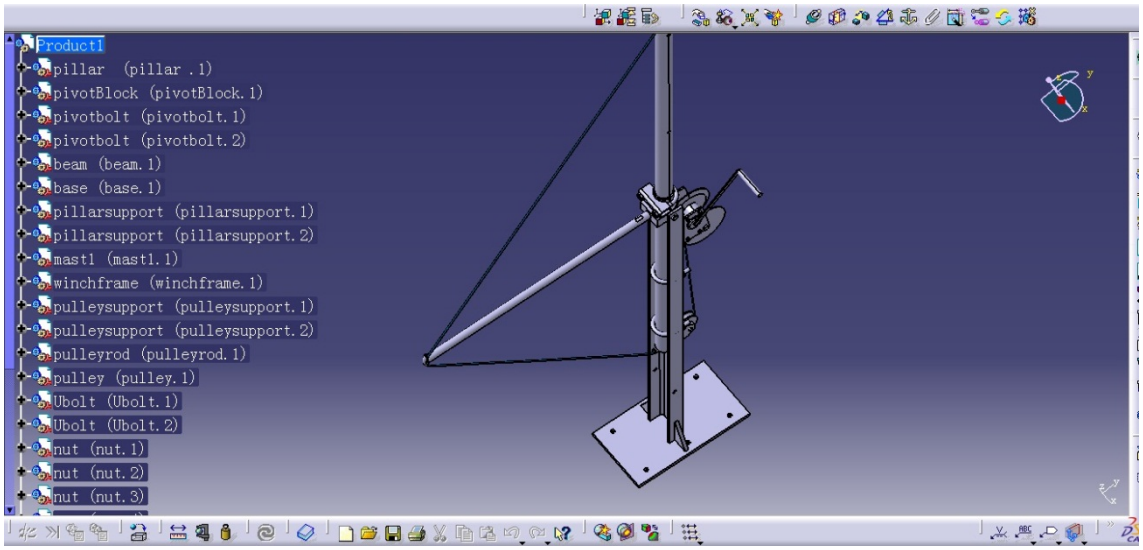


Figure 5-5 Suggested solution by D. Brown

In the new design, winch cable hooks a point that is 5m away from the pivoting point of the mast, and guided by a pulley and a short rod. The guiding rod is screwed into the mast holder which can pivot around the pin.

However, after showing the improved design to a radio amateur, Barry Walker, he pointed out that the design is not suitable for long term usage though the structure is able to support antennas and other accessories. Especially the winch will become dull after one year exposed outside. For safety reason, it has to be inspected regularly. Moreover, the diameter of the mast is too small. He suggested the top mast diameter should be at least 2 inches, while the current bottom mast is only 2 inches. And the structure will be placed on the steel structural roof for long term, thus it requires higher safety factor.

5.3.2 Final Solution

By suggestions, two 4 by 2 inches channels will be used as the mast support instead of one, and 3 inch diameter galvanised tube is selected for the lower part and 2 inch diameter tube for upper part. The structure will be welded to a 22mm thick steel plate which is bolted to the steel floor. The joint of 2 inch and 3 inch tube is a special designed adapter.

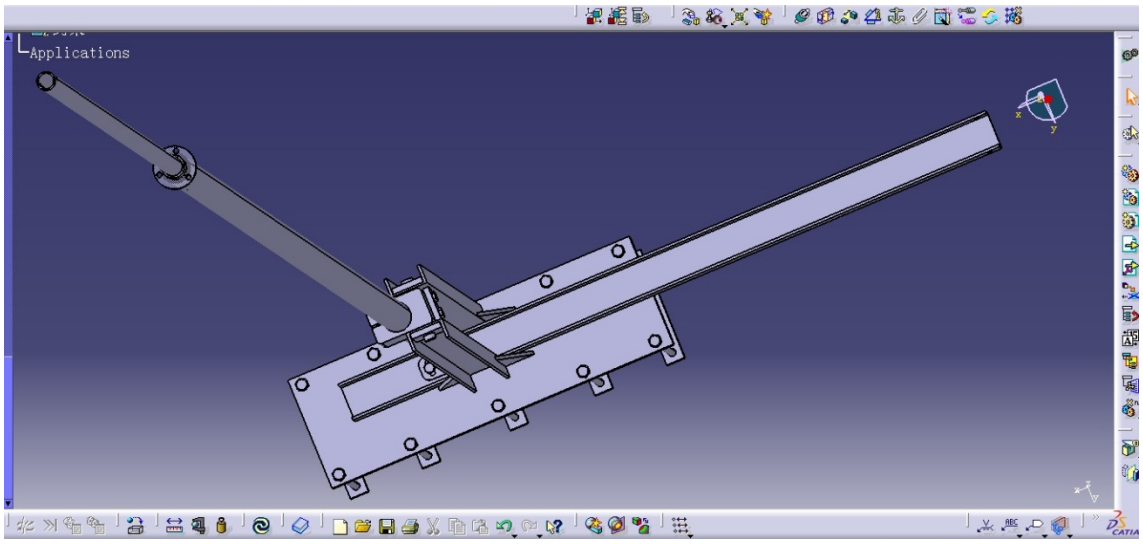


Figure 5-6 Final Solution

The complex component which needs more machining is the pivoting block. It holds the 3 inch diameter mast tightened by two M12 Allan bolts, while a cross

axis hole is designed for the Ø30mm pivoting pin with sliding fit. The initial material was planned to be stainless steel. However, aluminium alloy 6082 is found to be suitable for the application with comparatively low cost and high yield strength (300MPa).

The whole structure will be bolted on the beam of the floor by 10 pieces of M20 studding bolts. At height of 6m is the 3 guy ropes joined by a stainless steel ring, and on the top just below the amplifiers is another 3 guy ropes. The location of guy ropes and the antenna mast is shown in Figure 5-7 below:

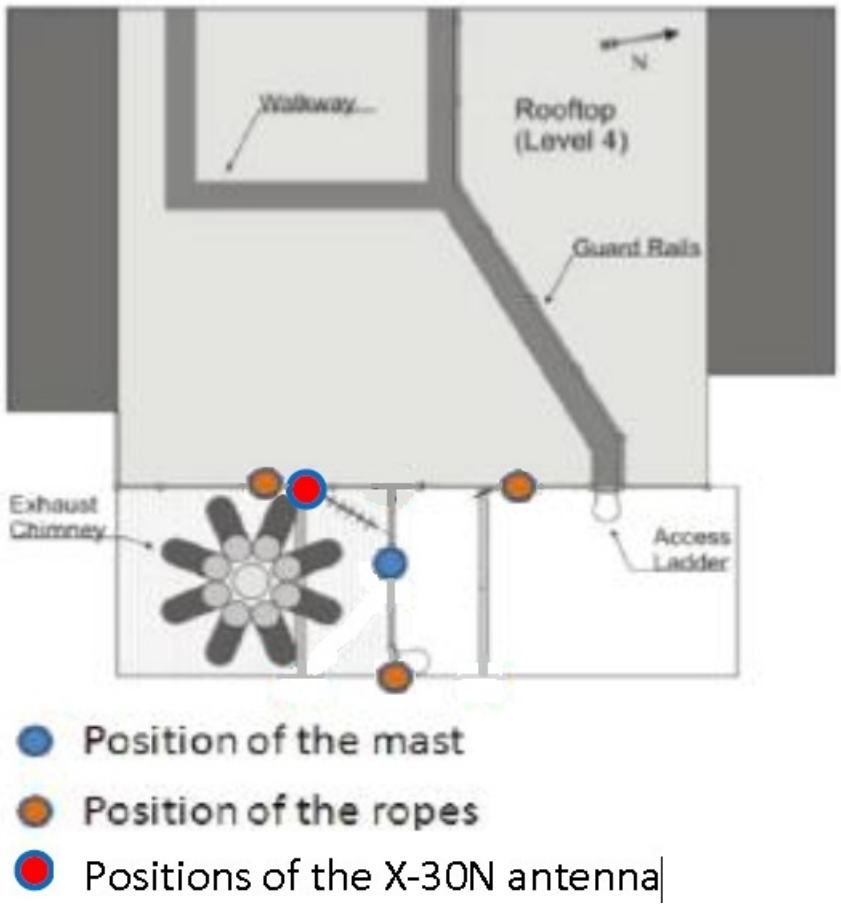


Figure 5-7 Position of antenna mast and guy rope anchor point

5.3.3 Strength Analysis

New structure was modelled in Catia which can be used for illustration and analysis. Moreover, manufacturing drawing of each component was generated from the models thanks to the powerful software. As the new design is the improved structure of the previous project, it is still necessary to analyse its

strength. Two main situations were analysed: initial lift-up case and strong wind case.

In the initial lift-up case, antenna mast is in horizontal position and ready to pivot up. The load at the end of the mast is close to 20Kg. During calculation 196N was used while the pulling force of hand winch was 1300N. These loads can be easily defined in GSA. For the other mechanical properties, such as the boundary condition and connection will be defined by the special features in GSA. For instance, clamp was set to the pin hole of the pivot block, while contact connection property was used for the connection of mast adapter with masts. And computer calculates the mesh size according to the geometry of the element, then the model was analysed.

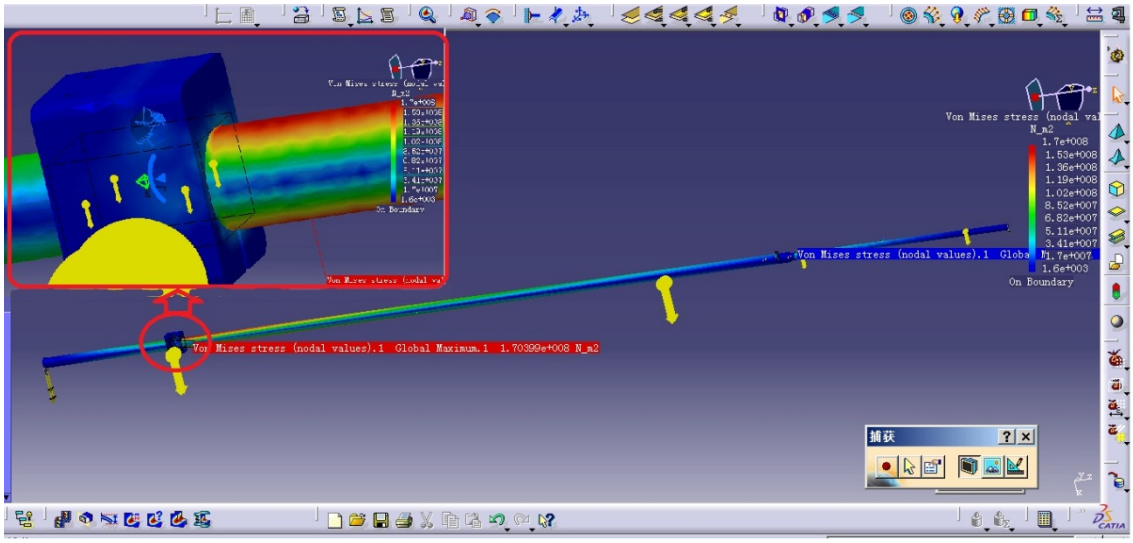


Figure 5-8 Mast Stress Analysis in Lift-up Case

The result shows that the maximum stress point is 170MPa which is close to the pivot block. Although this value is lower than the yield stress of steel, it is suggested to pull the guy ropes to reduce the stress on the mast during lift-up, especially the initial start.

While for strong wind case, the wind speed was considered at 160Km/h as the worst case. Under this wind condition, the drag of antennas is 48N and 74N respectively which can be found from the antennas user manual. The drag of masts and the rotator can be calculated by equation:

$$F = \frac{1}{2}\rho_{air} V^2 C_d S \quad \textbf{(5-2)}$$

Where F is the drag force, ρ_{air} is the air density (1.22Kg/m^3), V is wind velocity (160Km/h or 44.4m/s), C_d is the drag coefficient, S is the cross section area normal to wind velocity.

Drag coefficient for antenna mast is 0.8 and for rotator is 1.1.[22] Projected area of mast is S_{mast} = 0.0762m X 6m + 0.05m X 3m =0.6072m^2 and rotator is $S_{rotator}$=0.06m^2. Thus the drag force for mast and rotator can be calculated by Equation (5-2) above:

F_{mast}=0.5 x 1.22 x 44.4^2 x0.8 x 0.6072=584N

$F_{rotator}$=0.5 x 1.22 x 44.4^2 x 1.1 x 0.06=79.4N

Drag forces applied on the antenna masts were deemed as uniformly distributed force. It was applied by the Distributed Force feature in GSA, while the drag forces on the rotator and antennas were expressed by Force Density. The bolted connections were taken as Fastened Connection property and Seam Welding Connection property was used for welding connections. After all the mechanical properties were properly defined then the structure was ready for analysis.

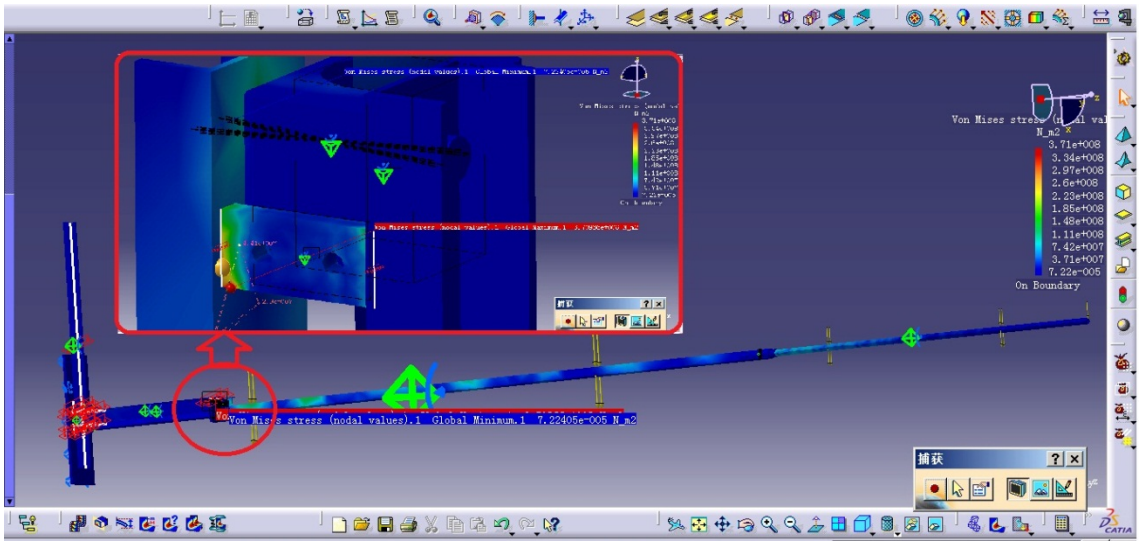


Figure 5-9 Structure Analysis

This analysis was done without the guy ropes as it can be seen how the structure can survive under the strong wind condition. The analysis result shows that high stress was concentrated close to the pivot block and the highest one was at the Fix Plate which was welded to the Channels. The maximum stress was 371MPa which was far beyond the mild steel yield stress. Hence, in the strong wind of 160Km/h the structure would probably fail from the Fix Plate and the point on the mast close to the Pivot Block.

In the GSA, it is easier to add frequency analysis after static analysis. It can estimate how the masts behave in the strong wind and what the possible vibration frequency. In principle, the frequency can be calculated by:

$$f = (V \times SN)/L \quad \textbf{(5-3)}$$

Where f is the vibration frequency, V is the flow velocity in metre per second, SN is the Strouhal Number (0.185 in this case), L is the diameter of the mast. In the current condition that two masts joined together by adapter and then fixed on the support plate by two channels, the software could model it easily.

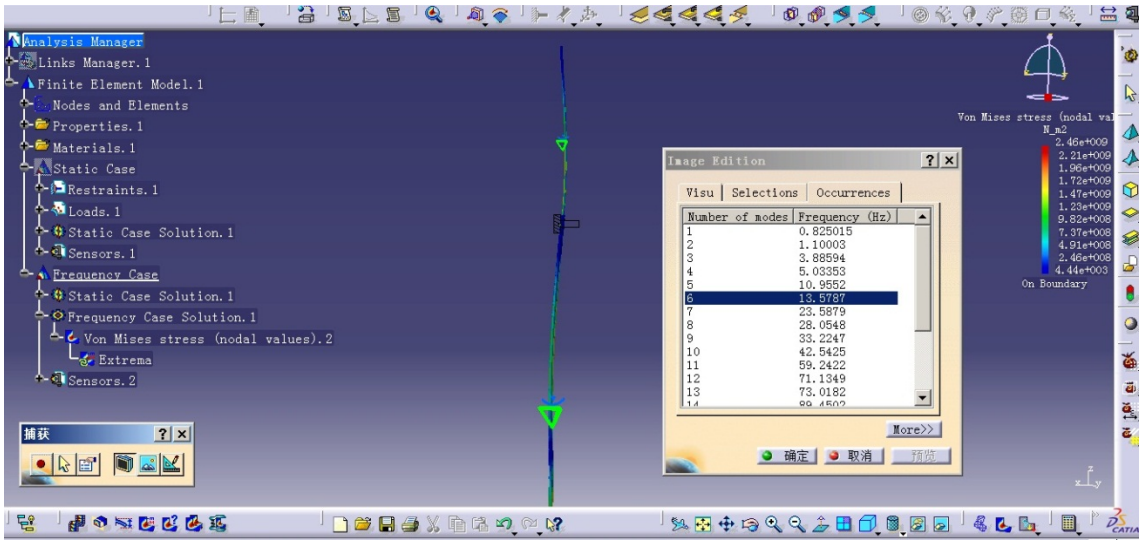


Figure 5-10 Vibration Frequency Analysis in the Strong Wind

Nevertheless, the situation will change when the structure is reinforced by 6 guy ropes. The breaking strength of 6mm Kevlar rope is rated at 4000pounds (14641N). Hence under 160Km/h wind, the ropes compensate the drag forces until the structure collapses. To be compatible with the circumstance, the

convenient anchor places for the ropes are at the hand rails where is the only allowed place to attach other objects, referring to Figure 5-7 (page68). The detailed guy rope fixation is shown in Figure 5-11below:

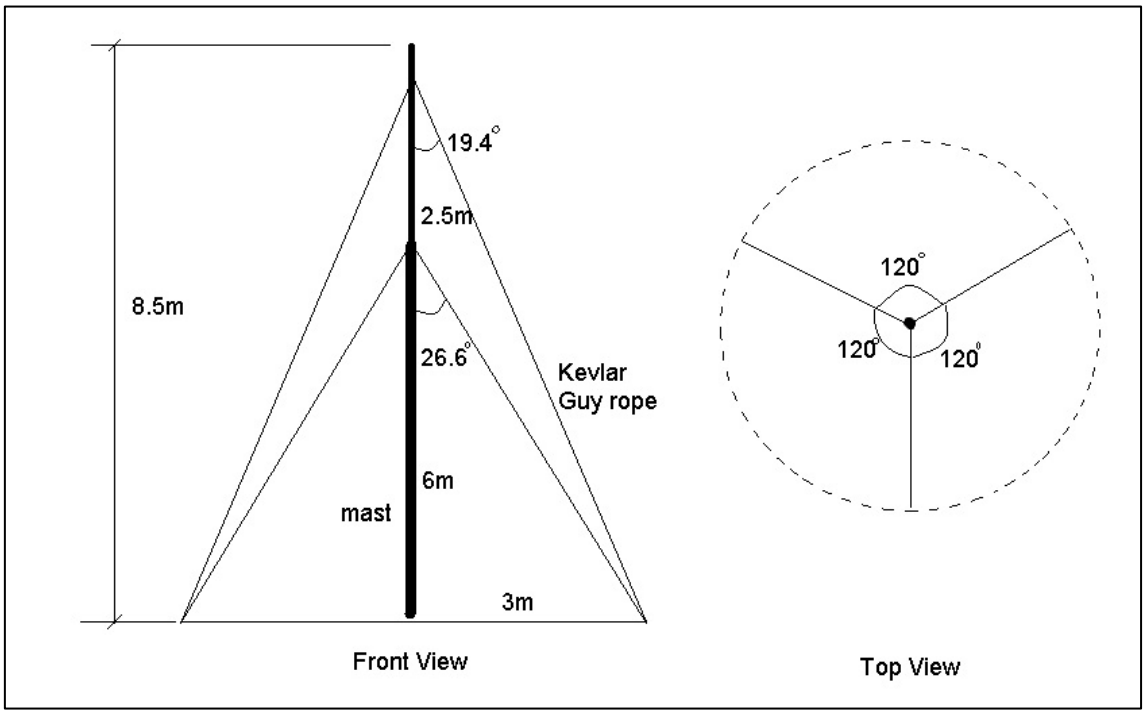


Figure 5-11Guy Rope Fixation Illustration

The worst case is only two guy ropes are taking the wind load. Assuming the tension on longer rope is T_L and shorter one is T_S. The sum of the drag force of the masts, antennas and rotator is 784N acting horizontally. Then the tension on the rope can be calculated by:

T_L x sin26.6 x cos60 + T_S x sin19.4 x cos60 = 784

T_L / T_S = 9 / 6.71

Thus T_L = 2278N and T_S = 1700N which are far below its breaking strength (14641N).

5.4 Summary

The work was first carried out was to enable the pivoting function of the antenna mast. Two solutions have been designed: counter weight and hand operated winch. The latter one was selected and improved for the convenience of

installation and operation. However, the design of the structure was considered to be neither sustainable nor safe enough. Finally, a reinforced structure was designed with suggestions from other professionals and analysed in Catia GSA. The analysis shows the structure has better performance than previous ones. The approved design then was provided with detailed drawings which were made for manufacture.

6 INSTALLATION

By the time of writing this chapter, the mechanical design of the mast support has been confirmed and it is under manufacturing, the last order has been made and all the parts needed are gathering together, all the signs show the project is approaching the installation stage. As the installation consists of indoor and outdoor work, main types of installation work are electrical connection and mechanical assembly. Especially the mechanical assembly work will be carried out on the roof. Thus it is necessary to emphases the safety issues before work both for indoor and outdoor.

6.1 Risk Analysis

Risk analysis is the process to predict and define the hazards, and evaluate the probability of occurrences to prevent or avoid the body injury or any accident. In this installation work, improper or imprudent action not only can cause equipment damage, but also body injury. Thus the potential hazards are assessed for both indoor and outdoor work.

Due to the mechanical installation at height, there is safety risk in several aspects. The primary one is work at height where falls have a high probability. In fact, the safety training is arranged for persons who will work on the roof. Compulsory equipment will be used or worn to prevent fall accident. The secondary is body injury from crashes, clamps and slips. During last project study, Soyer did risk assessment for the installation process.

For electrical equipment installation, the main power should be kept off to avoid any electric shock. It is also useful to set minimum power for testing to minimize any damage of equipment by probable wire misconnection.

nb	What are the hazards?	Who will be harmed?	How will they be harmed?	What controls are already in place?	What further actions are required?	How will RA be put into action?
1	Working at height.	Students erecting antenna	Falls	Edge protection	Remain within the barriers and enclosed areas.	Training, instruction.
2	Working at height.	Students erecting antenna	Falls	Edge protection	Obtain permit to work to ensure Estate are aware operatives	Permit to work from Estate.
3	Slips and trips	Students erecting antenna	Slipping on wet surfaces and ladders.	Gratings on floor of plant areas, none on roof	Wear suitable footwear.	Inspection, training, instruction.
4	Slips and trips	Students erecting antenna	Tripping on materials and tools	None	Keep tools and equipment in one place.	Good housekeeping
5	Blows to head	Students erecting antenna	Banging head on ladders and steel work whilst climbing. Tools and materials falling	None	PPE - hard hats, bump caps. Keep tools and equipment in one place.	Provision of PPE, training, instruction. Good housekeeping
6	Adverse weather	Students erecting antenna	Cold, wind, lightning.	None	Stop work and return when weather conditions improve.	Site discipline.
7	Cuts and abrasions	Students erecting antenna	Cutting materials and fixing to structure	None	PPE - gloves, eye protection, Tools and plant - correct tools and equipment to be used.	Provision of PPE, training, instruction.

8	Lone working.	Students erecting antenna	Nobody to know if accident occurs or problems arise.	None	NO LONE WORKING ALLOWED	NO LONE WORKING ALLOWED
9	Electric shock	Students connect electric power	Touch the live line by mistake	Protective Earth	Keep main power off	Check power before wiring work
10	Short circuit	Equipment damage	Cable broken, misconnection	none	Use New cable Small power for testing	Visual checking Meter measurement

Table 6-1 Risk Assessment of Installation Work (extracted from Soyer's thesis)

6.2 Electrical connection

6.2.1 Device Arrangement Layout Design

Devices in indoor section will be kept in a cabinet which will be placed at the third floor corridor of B52. From the cabinet the coaxial cables and control cables run out and follow the cable runway out of the building. The radio should be placed on the top of the shelf so that the length of the coaxial cable will be as short as possible to minimize the possible interference. The computer case will be put at the second shelf while the power controller is at the bottom. The devices' arrangement is shown in Figure 6-1 below:

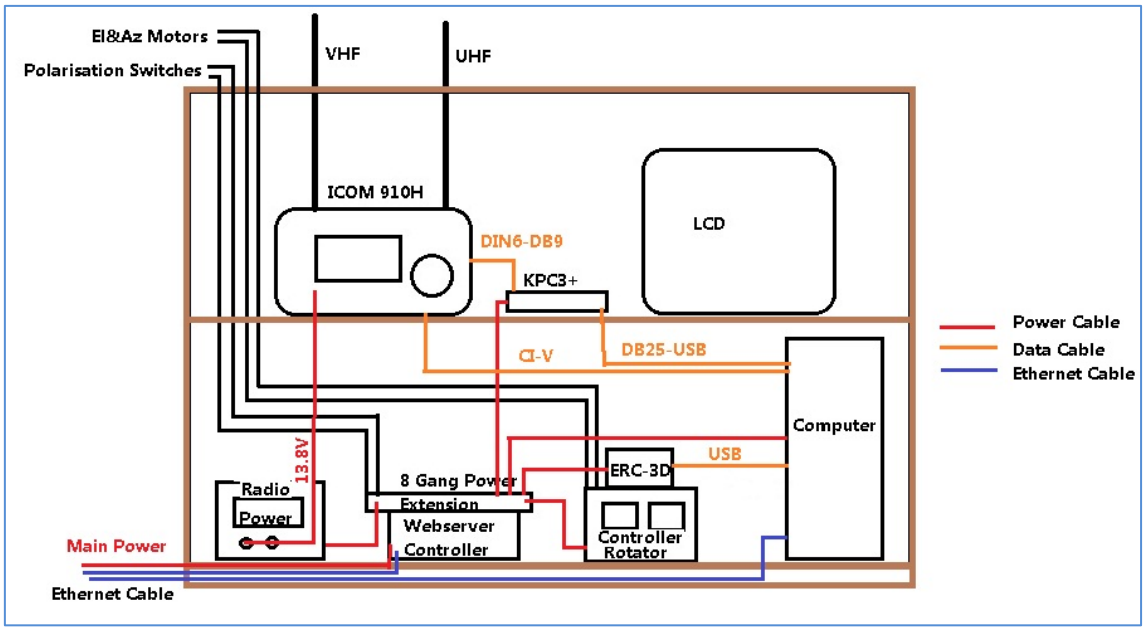


Figure 6-1 Equipment Arrangement Layout (Front View)

In the above arrangement, Electromagnetic Compatibility (EMC) was considered to minimize the opportunity of interferences among those devices. As the radio emits powerful radio signals, any metals, wire or cable may pick up the signals and convey them to susceptible devices. In case there is interference, signal can be picked up by the power cable, data cable and the electronic devices. To increase the immunity of interference of the system, ferrite ring filters are used where the power leads and cables enter the devices. [23] Two types of ferrites were bought from Maplin shown in Figure 6-2 below:

Figure 6-2 Ferrite Ring and Clip-on Ferrites

6.2.2 Cable Assembly

There are 8 cables connect the indoor and outdoor systems, including:

- 2 pieces of 4-core screened power cable for polarisation switches
- 2 pieces of 7-core power cable for Az&El motors
- 1 piece Ethernet cable for IP Surveillance Camera
- 3 pieces of RG-213 Coaxial cable for antennas

The Ethernet cable has to follow a separate route to the roof depending on the position of the camera where it can see the X-Quad antennas entirely, while the remaining cables go to antennas by the same route. All the terminals of the cables on the mast are protected by shroud to against water. For power cables, each wire is connected to screw terminals or clamps of the devices in the cabinet, while for the coaxial cables special care was taken to make sure the high power radio signals are confined within the cable shield. There are two types of connectors used for the coaxial cable: PL259 and N type connectors. Both of them are suitable for RG-213 cable with pressure sleeve which means no soldering needed to connect the copper braid shield. Copper braid was flattened backward against the sleeve and then tightened by the screw. However, the core twisted strands have to be soldered to the centre pin. Especially, for N type connector, the centre pin is too small to hold the strands. Hence two wires were cut off in order to fit the pin.

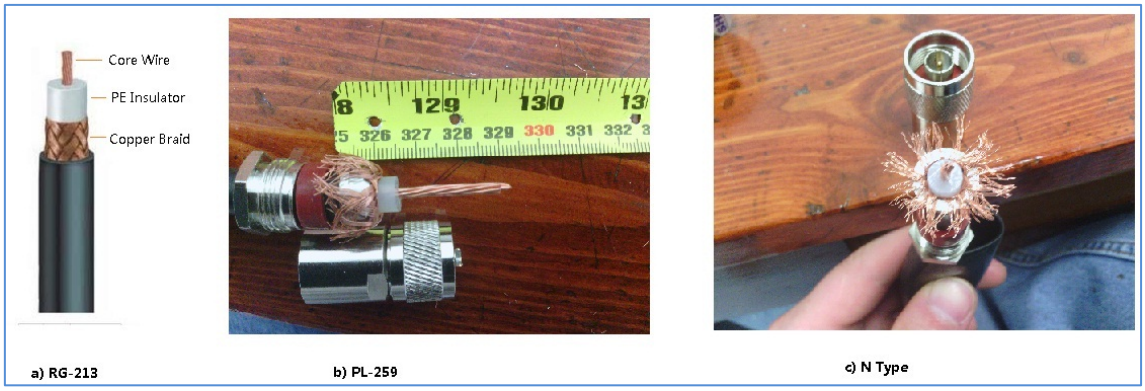


Figure 6-3 a) RG-213 Coaxial Cable b) PL-259 Connector c) N Type Connector

6.2.3 Polarisation Switches and Antenna Connections

Polarisation switches used for VHF and UHF respectively has three N jack and one 6pin MIC connectors. 6-pin MIC plug was configured as follows:

6-pin MIC Connector		
Pin No.	Polarisation	Wire Color
Pin1	Circular right	red
Pin2	Circular left	yellow
Pin3	n.c.	
Pin4	GND	blue
Pin5	horizontal	white
Pin6	n.c.	

Table 6-2 6-pin MIC Connector Wiring Code

From above table it can be seen that Vertical is not connected. In fact the polarisation switch is designed to be Vertical polarised when there is no voltage applied on it.

The three N jacks: one is for Horizontal plane of antenna and one is for Vertical plane, while the last one goes to the Pre-amplifier. In order to get antenna polarised properly, correct length of the coaxial cable has to be made according to it user manual. [24]

- **VHF**-both cables must have the exact same length
- **UHF**-the cable to Horizontal plane must be 112mm longer than Vertical one (it is calculated by L/4 x velocity factor = 700/4 x 0.66 = 112mm for PE insulated cable) [*velocity factor is defined as the speed ratio of electric travels in the cable comparing with the speed of light. Obviously, cable will slow down the speed of electric*]

6.2.4 VSWR Measurement and Antenna Tuning

All PL-259, N type connectors, coaxial cable, preamplifier, polarisation switch and antennas have a characteristic impedance 50Ω. If all are matched, which the system is designed to be, the feedpoint impedance is 50Ω no matter how long the connection cable is. And the system is so efficient that most of the power is transmitted by the antenna. Otherwise, some power will be reflected

back by antenna and may damage the transceiver.[25] The portion of reflected power depends on how much the mismatch is. The reflected wave is superimposed on the forward wave and forms a so called Standing Wave. Thus the voltage component of the standing wave consists of voltage component of reflected wave (V_r) and voltage component of forward wave (V_f). The ratio of V_r and V_f defines the Reflection Coefficient which is a complex number and its magnitude ρ ranges from 0 to 1.

$$\rho = \left|\frac{V_r}{V_f}\right| \tag{6-1}$$

The Voltage Standing Wave Ratio (VSWR) is then expressed by following equation:

$$VSWR = \frac{V_f + V_r}{V_f - V_r} = \frac{1+\rho}{1-\rho} \tag{6-2}$$

Thus it is necessary to check if the system is matched. The instrument used to measure VSWR is AVAIR AV-1000. It can operate at frequency range1.8 - 160MHz and 430-1300MHz. Its connection method is shown in Figure 6-4 below:

Figure 6-4 VSWR Measurement

VSWR	Reflection C_f ρ	Reflected Power (%)	Reflected Power (dB)
1.0	0.000	0.00	-Infinity
1.5	0.200	4.0	-14.0
2.0	0.333	11.1	-9.55
2.5	0.429	18.4	-7.36
3.0	0.500	25.0	-6.00
3.5	0.556	30.9	-5.10
4.0	0.600	36.0	-4.44

Table 6-3 Relationship of VSWR, ρ and Reflected Power

For an ideal system VSWR is 1.0. In practice, 1.5 is acceptable and 1.1-1.2 is deemed as a good system. After the X-Quard antennas are connected, normally only minimum adjustment is needed. For fine tuning of SWR the ends of first director can be bent. Always bend both ends of the director.

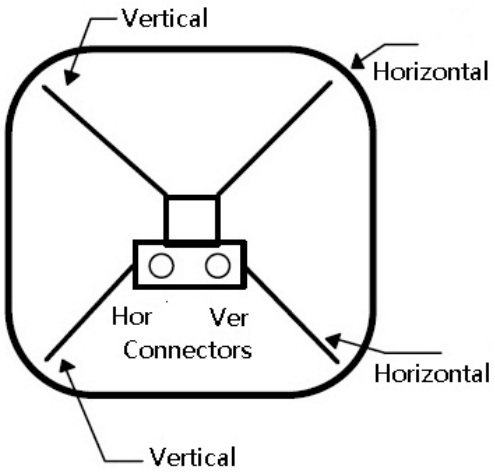


Figure 6-5 Wimo X-Quards Tuning Method (seen from back of antenna)

As shown in Figure 6-5 above, for adjusting of SWR of Vertical Plane, bend the left ends of the first radiator forward or backward of the antenna [17]:

- Bend towards radiator will shift the resonant frequency downward
- Bend towards second director will shift the resonant frequency upward

One thing has to be mentioned is the Common Mode Current which could affect the SWR. It usually happens with balanced antenna connected with the

unbalanced feed line for dipole or loop antenna. As a result, some current from antenna flows back to the coaxial shied and radiates. Thus SWR will change when there is disturbance on the shield, e.g. rain. One way to eliminate this effect is to use a so called Coax Choke close to the antenna feedpoint. However, thanks to the design of the X-Quards, this won't happen as the antenna is unsymmetrical referred to the coaxial cable feed line. This was confirmed with Wimo's technician, thus no Choke is needed in the feed line.

6.3 Mechanical Installation

6.3.1 Mast Support Installation

All the parts of the mast support structure are manufactured in the mechanical workshop. And they are also pre-assembled to ensure the installation work on the roof. Mechanical technician, Derek Brown, will mainly carry out the work.

The support structure will be placed at the edge of the floor where there is strong beam underneath. As it can be seen in Figure 5-7 at page 68, three guy ropes at one height are separated by 120° horizontally. And the anchor points are assigned in such a way that one is close to the access ladder while the other two are at opposite side hand rail due to easy access. Moreover, the guy ropes should be kept in same tension at same angle with the mast during service. Hence there is only one point along the edge of the floor that the mast could be placed. The position can be calculated according to the triangle relationship shown in Figure 6-6 below:

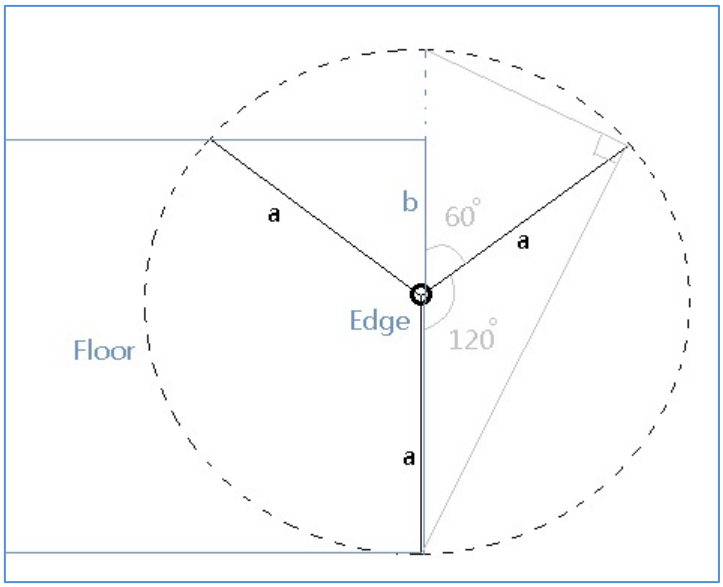


Figure 6-6 Mast Support Position Illustration

The length **L** of the floor edge is **a** + **b** = 1.5**a**, thus **a** is 0.67 of the length **L**.

First, the 22mm thick base plate will be bolted on the floor by M20 studding bolt. In order to ensure the upper structure to be vertical, the base plate has to be mounted horizontally. Level ruler may be used to check its level. Second, two Standing Channels are mounted vertically. The alignment has to be checked so that the Pin Rod can go through two channels with tight tolerance. At last, the Fix Plate and Angle Iron Support are attached to reinforce the structure.

6.3.2 Mast Assembly

The 3” mast is jointed with 2” mast by the Mast Adapter, and then locked together by a Ø8mm Pin. Gaps can be sealed by silica gel to prevent rain.

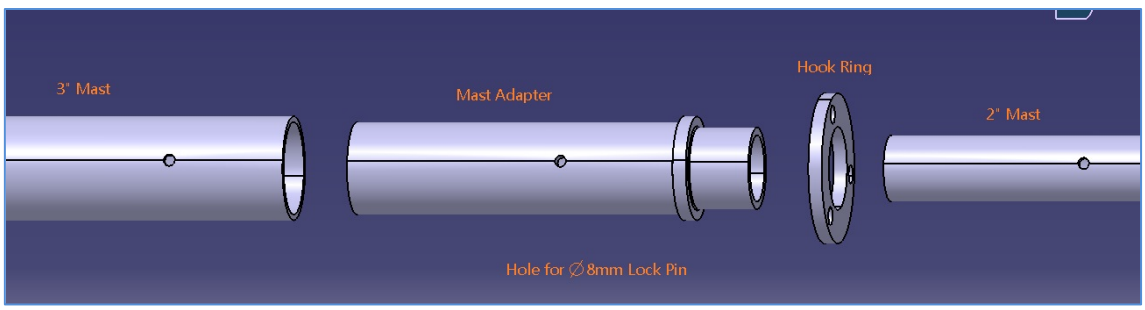


Figure 6-7 Masts Assembly

Mast should be in vertical position. It can be inspected by Leveller from two orthogonal directions. In case there is deviation to vertical, then it can be adjusted by the guy ropes.

6.3.3 Rotator Installation

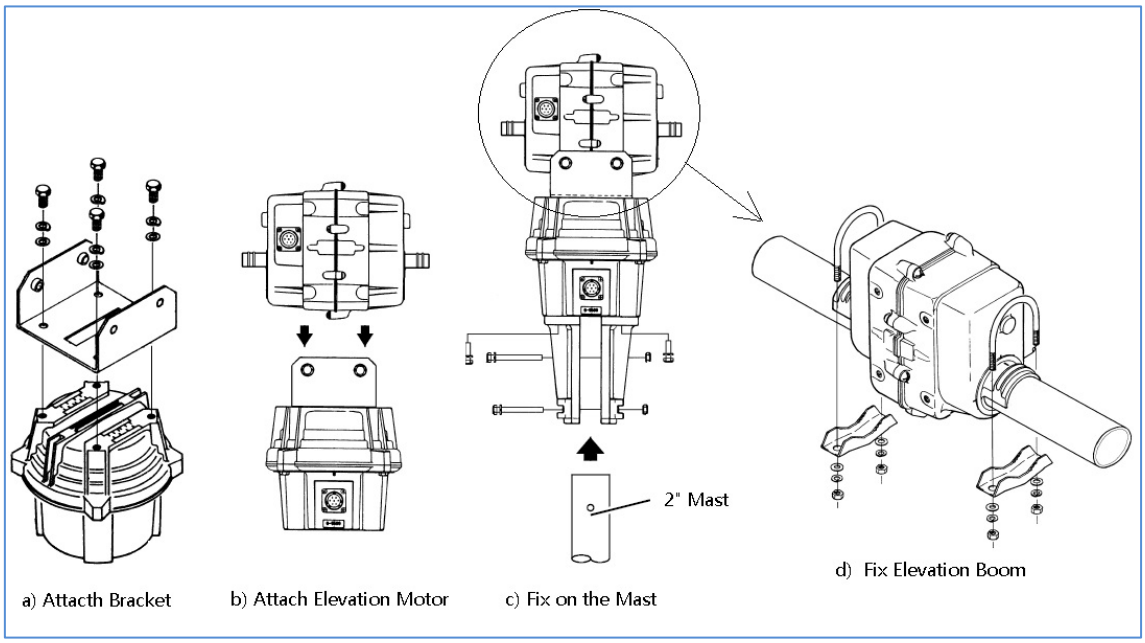


Figure 6-8 Rotator Assembly on the Mast (Extracted from [26]**)**

Rotator is fixed on the mast when the mast is lying on the hand rail following the steps shown in Figure 6-8 above. Initially, 0 of the Azimuth motor should be set to the North. This can be adjusted by rotating the 3” mast inside the Pivot Block with compass before tightening.

6.3.4 Antenna Installation

Wimo’s X-Quads were assembled according to the instruction. The VHF and UHF antenna will be mounted on the two ends of a 1.8m boom through the rotator. As the weight of VHF antenna is 2.3Kg and UHF one is 1.6Kg, in order to balance the boom relative to the rotator, VHF has to be 0.74m to the centre of the rotator.

Two antennas are designed to be foremast mounted on the boom by the clamps. Before tightening clamps, antennas’ direction must be perpendicular to the mast, which means the initial elevation angle is 0 once the mast stood up.

6.4 Lightning Protection and Grounding

Lightning protection and grounding is important for safely using the ground station. This matter is considered for worst case when lightning strikes the antenna or power supply, there is a dedicated path to convey the surge current to ground effectively. The lightning strike situation is illustrated in Figure 6-9 below:

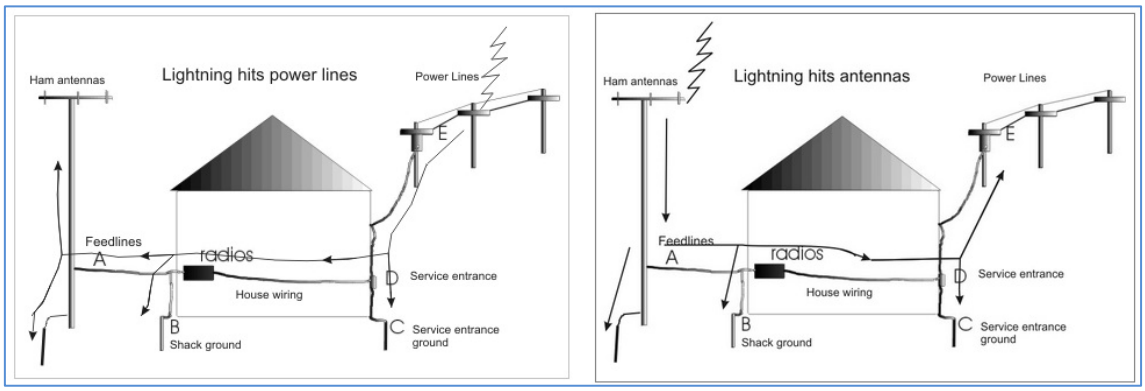


Figure 6-9 Lightning Strike Illustration (Extracted from [27]**)**

Concerning these two possible paths of the surge current, fully protection was designed for the ground station. For the main power supply, Brennenstuhl Primera 4.5KA Single Silver Mains Plug Socket is used. Moreover the 8-way power extension board is also surge current protected with response time 50ns. There are also three Ethernet Surge Protectors for the Ethernet cable to the control computer, Webserver Controller and IP camera. All these protectors are grounded to a common Earth cable.

Connections from antennas are also fully protected. Three coaxial surges are for the coaxial cables. Three rotator shunts are used for the power cables. These protectors are attached to a copper bar inside a junction box which is weather proof. The copper bar then is connected to the Earth cable of the building.

7 CONCLUSION

This thesis project finalized the previous project study and implemented the required features into the ground station. At the beginning of the project, every device was studied concerning the connection method and working principle, also wiring method. Especially, the customised connection cables were carefully manufactured.

The first study was KPC3+, as it has two connection cables: one to computer and another one to the radio which is a customised one. The customised cable was configured for 1200bps AFSK communication which is the maximum data rate of KPC3+. The correct wiring and firm soldering will ensure stable connection hence smooth operation. TNC was connected to Hyper Terminal of the control computer and also the test of its connection to radio was carried out by CAL (calibration) command. However, the TNC can not be successfully recognised every time by Hyper Terminal. Instead, Packet Engine Pro is very smoothly connected, even with baud rate and Port auto-detect function. The test was done with its trial edition as it charges 49$ for registration.

Soldering and wiring of ERC-3D was also checked as it is an assembled device from the original kit. Some points were re-soldered and wiring was re-connected. It was first connected to its service tool that provided in the kit and then calibrated by the method which was written in Appendix E of Soyer's thesis. Meanwhile, Ham Radio Deluxe was updated to 5.1 version and the HRD Rotator was configured with ERC-3D and G5500 rotator. Finally the readings of Elevation and Azimuth are same for ERC-3D, Rotator Controller and HRD Rotator, which means the antenna directing system can work properly. At the end, ERC-3D was installed in an aluminium enclosure.

Another omni-directional antenna was bought for test. Before the test, IC-910H was connected to updated HRD. The actual test was done with the mobile radio FT-817N and a small signal reception system was set up. Testing candidates were HO-68, CO-55, CO-56 and CO-68 as they are currently operational and have continuous CW beacon. However for AFSK beacon, ISS was chosen for

the test. Their schedules were predicted by HRD Satellite Tracking. And the testing point was 52°4.50'N and 0°37.89'W at the large sports field in front of the main reception as there is good field of view without large obstacles. The test was first done with CW beacon reception. Beacon signals received successfully from HO-68 and CO series cubesats and recorded for post-processing. However, only one segment of HO-68's beacon was decoded. The experience of manually adjusting frequency to compensate the Doppler Effect was acquired and Long's calculation of the adjusting range (± 10 KHz) was verified [14]. AFSK beacon reception was also successful. The decoded information showed that the messages forwarded by ISS were actually transmitted by the nearby APRS stations. Reception trials to CO series Cubesats were done but no success which means without high gain antenna and LNA it is impossible to receive the AFSK signal from them.

After the test, the project continued to mechanical design of mast support phase. Pivoting function of the antenna mast was the main objective which was required for easy installation and future maintenance. The preliminary design was based on the previous bought mast. As the inconvenience of accessing to the roof, there was no site survey until the preliminary design was done. Two designs were made: Count Weight Solution and Hand Winch Solution. The latter one was chosen as the simple structure and easy manufacture. After the roof survey, it was modified. The mast would pivot at a point 1.2m above the floor and it would be placed close to the chimney where there is a beam underneath the floor could be attached. The winch will be fixed at the back of the channel and pull the bottom of the mast. However the strength analysis showed that the aluminium mast doesn't have that strength to afford the pull force, which means it needs extra support during lifting up. In this case, the winch won't help too much as the goal is to handle the lift up or down by one person. A brilliant idea was suggested by Derek Brown that the pulling point was moved to the middle of the mast instead of the bottom and the winch was at the same position with guided rope. This solution was consulted from an amateur radio professional. With his rich experience the winch was not suggested to use as the bad outdoor service performance. And the structure

was safe but not sustainable for long term. Thus the design should be reinforced and winch could be used but not exposed outside for long. A 6m long 3” Galvanised tube is used for lower mast and a 3m long 2” one is for upper part. Two channels are to support the masts holed by a special designed pivot block. The initial plan was to weld two channels to a 22mm thick plate to reduce the assembly work and keep the precision of the pivot pin joint. However, the welded structure was about 100kg and renting a crane to lift it will be very expensive. Therefore the base plate was slightly modified to smaller one and two channels will be bolted on it. Four extra Angle Iron bars from each side will enhance its strength.

Another main objective was to remotely control the ground station. As the radio and the rotator can be controlled by the control computer, desktop remote control software was required for the operation. After comparing the existing software, Splashtop was selected for the application as the better performance.

However, to fully control the ground station, the power of every device should also be controllable. IP Power Switch was chosen to control the power and purchased during previous project study. But its power outlets are IEC320 standard that require adapter for UK AC power plug. Beside the power control, newly bought polarisation switches were also expected to be remotely controlled. Suggested control device is a 4-way single axis rotary switch which is not provided in the delivery.

In order to enable remote control, Aqua Multiswitch was studied for the application, which is originally used for computer cooling fan control. It can control up to 8 channels with control software. In this case, the operation complexity just increased.

A thought was inspired by the IP switch which uses webpage as a control interface to control on/off action. In principle, this function is same for polarisation switch and power switch. The difference is that the handling voltage. Relay can be used for on/off action with large voltage handling range. And to control the relays, a webserver has to be built. Arduino microcontroller with Ethernet Shield was studied as it is an open source community. As this part of

study was not compulsory for this project, the development started with self-interest. Another drive of this study was that it may also be possible to control the radio by controlling a servo, as the radio power button has to be manually pressed to start.

At the beginning, Duemilanove with Ethernet Shield were used to set up the webserver. The servo and relay control was successfully embedded into a simple webpage running in the webserver. Thanks to its powerful library, the webserver is able to auto-configure DHCP IP. Once the new IP was assigned, it can be printed out in Serial Monitor. However, this could increase the inconvenience of operation. After consulting IT department, a fixed IP address could be set to the webserver, hence, it is not necessary to print IP in Serial Monitor.

Meanwhile, the solution was accepted and it was decided to expand the application. Thus the control command for power switch was written in the microcontroller. But due to its memory limit, the Mega2560 board with bigger memory was used. Finally all the switches are controllable except the power of the control computer. It has to be pressed when starting. Several methods have been studied. For example, Wake-On-LAN can power on the computer through internet by sending a so called Magic Packet, but this method was not suggested by IT specialist. The simple way used was to configure the BIOS of the control computer, as its motherboard has a function called Restore on AC Power Loss, to be able to auto start once power restored. At the end, the ground station can be fully remotely controlled.

Lightning protection and grounding system is important to the safety of the ground station. The connection between indoor and outdoor system is protected. The connection has 3 coaxial cables and 4 power cables in total. 3 coaxial cables are protected by the coaxial surges and 4 power cables are connected to rotator shunts. The coaxial surges and rotator shunts are placed inside a weather-proof junction box which is located close to the mast. Main power supply of the ground station is power surge protected while internet cable is

protected by Ethernet surges. One dedicated ground cable joins all the protectors and is connected to the main ground of the building.

Before the final installation, some connection coaxial cables were prepared in advance. These cables were assembled with N type and PL259 connectors protected by shrouds. Its conductivity was examined with multimeter.

By the time of writing this report, there is still no confirmation made about the safety training to access the roof again. However, during installation three issues have to be emphasised. First, the rotator has to be calibrated that 0 of azimuth is the North and 0 of elevation is horizon. Second, SWR has to be measured once the mast stood up and all connections are done. SWR 1.5 of the system is acceptable, while 1.1-1.2 is the main goal of fine tuning of the antennas. At last, six guy ropes reinforce the mast with certain tension. Meanwhile, the mast has to be ensured to be vertical and the boom has to be kept horizontally so does during rotation of the azimuth motor.

8 FUTURE DEVELOPMENT

8.1 AG-2400 Frequency Down Converter

Some Cubesats operate at S band for much higher communication data rate, e.g. CanX-2 has 256kbps BPSK data rate at 2.2GHz.[9] To increase the data rate capability of the Cranfield Ground Station, UX910 units were purchased for L band data communication. Moreover, AG-2400 Frequency Converter can be considered for S band operation. It converts the received 2.4GHz signal into 144MHz. This process is compatible with the ICOM 910H radio. With this radio, AG-2400 allows the **US** (Uplink/Downlink: 430MHz/2400MHz) mode operation. If UX910 unit is installed in the radio, then it also possible to operate at **LS** (Uplink/Downlink: 1200MHz/2400MHz) mode.

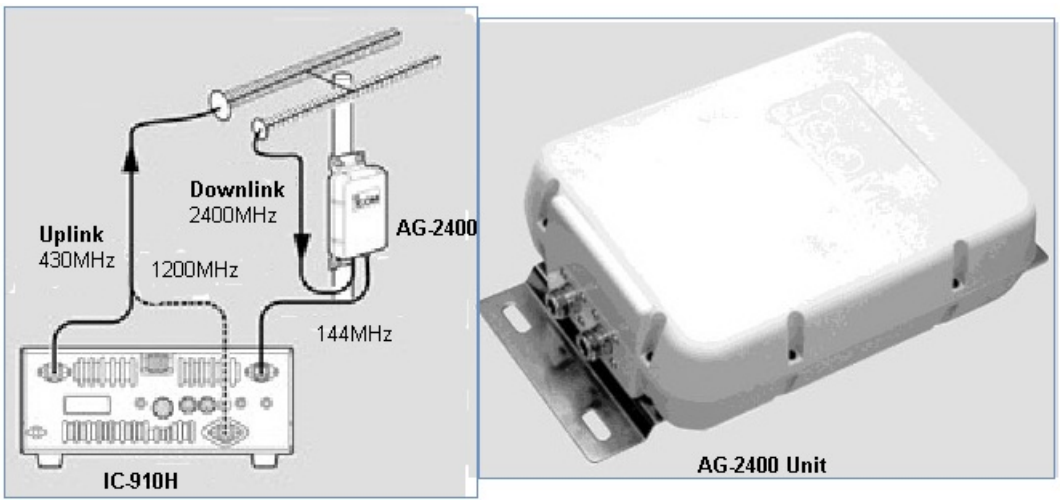


Figure 8-1 AG-2400 Frequency Converter for IC-910H radio

8.2 KPC-9612+ Packet Communicator

The current station is capable to communicate with Cubesat at 1200 bps AFSK which is restrained by KPC3+. KPC3+ is a single port TNC with maximum 1200bps data rate. Hence it can only be used by either VHF band or UHF band. This means the signal of only one band can be modulated or demodulated. However, for IC-910H **Satellite** mode, VHF band is for uplink and UHF band is for downlink. In order to modulate the tele-command in VHF band, meanwhile demodulate the telemetry in UHF band, another TNC is desired. KPC-9612+ is

a dual ports multispeed TNC which is capable for **Satellite** mode operation. Moreover it supports high data speed up to 38400bps. This could be compatible with AG-2400 working with the ICOM-910H radio for high data rate operation, e.g. downloading image data.

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APPENDICES

Appendix A User Manual

A.1 Introduction

This user manual consists of three segments: setup&configuration, Operation and Trouble shooting.

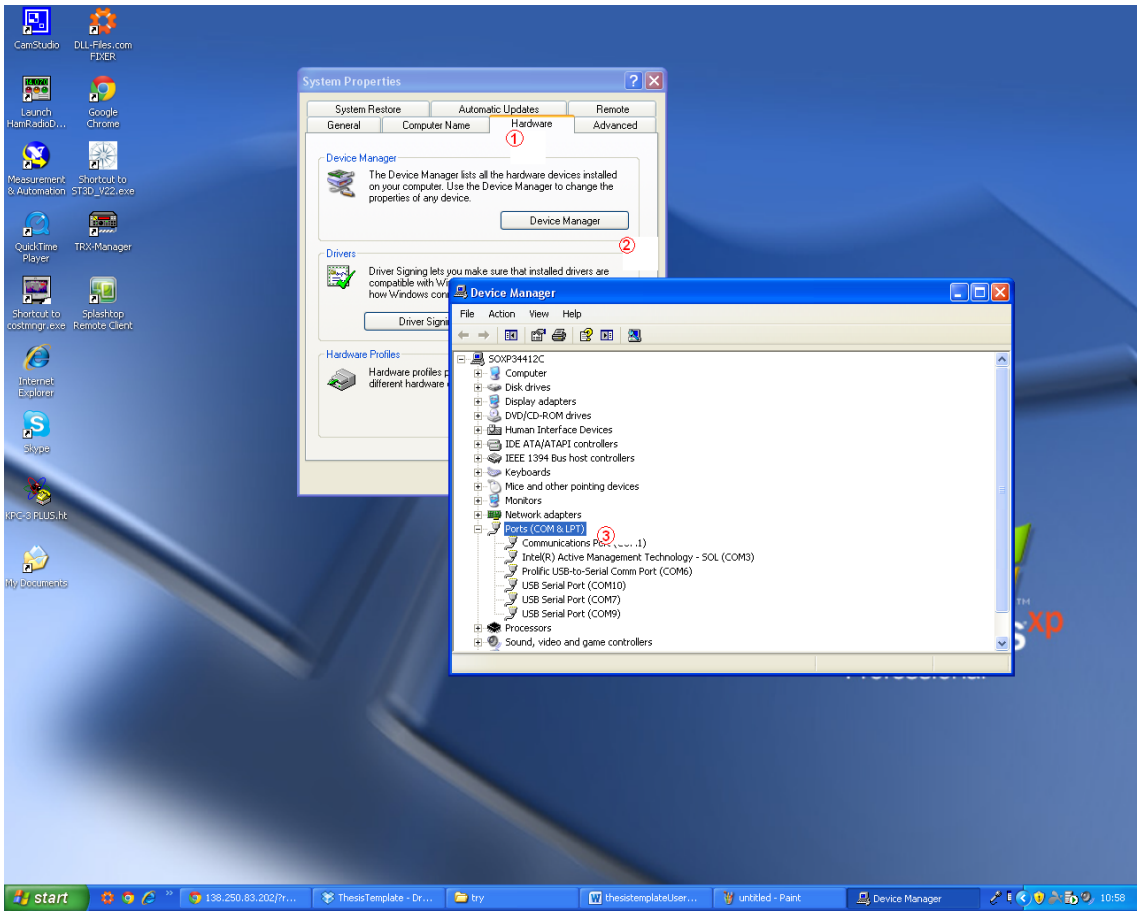
A.2 Setup & Configurations

A.2.1 Checking Port

The control computer of the Cranfield Ground Station has only USB ports, so those devices require old standard COM connection will be connected through a COM to USB convert cable. This cable thus can emulate COM poet while with USB connection.

A newly connected device or re-plugged in a different USB port, the port must be checked out as most of control software don't update the communication port automatically.

The easier way is: **Start** > right click on **My Computer** > **Properties** > **Hardware** > **Device Manager** > **COM**



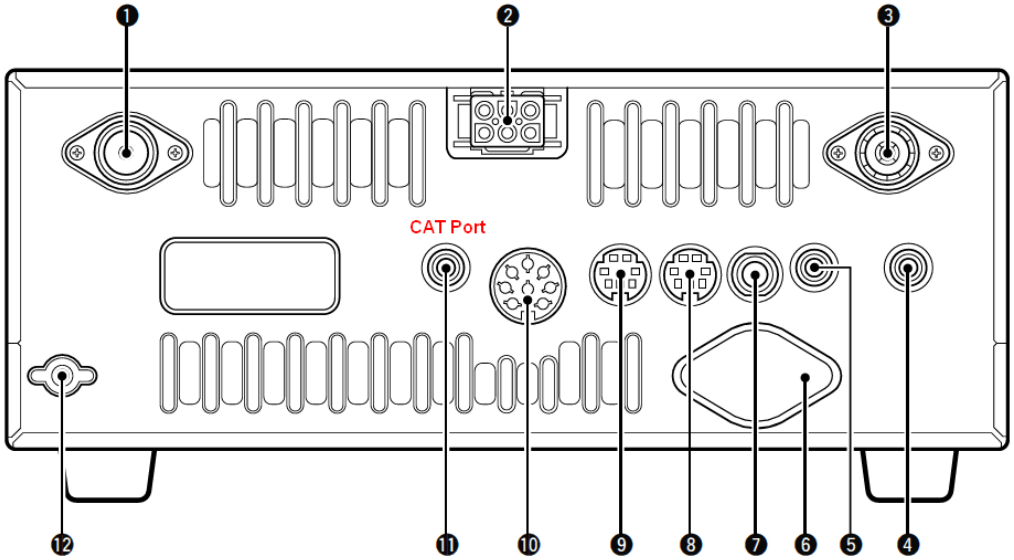
Other way to access is : **Start** > **Control Panel** > **Hardware** > **Device Manager** > **COM**

A.2.2 Ham Radio Deluxe Connect to IC-910H

IC-910H can be connected to computer by CAT cable- originally CT-17. However, in this GS, a CAT cable is used which is identical to CT-17.

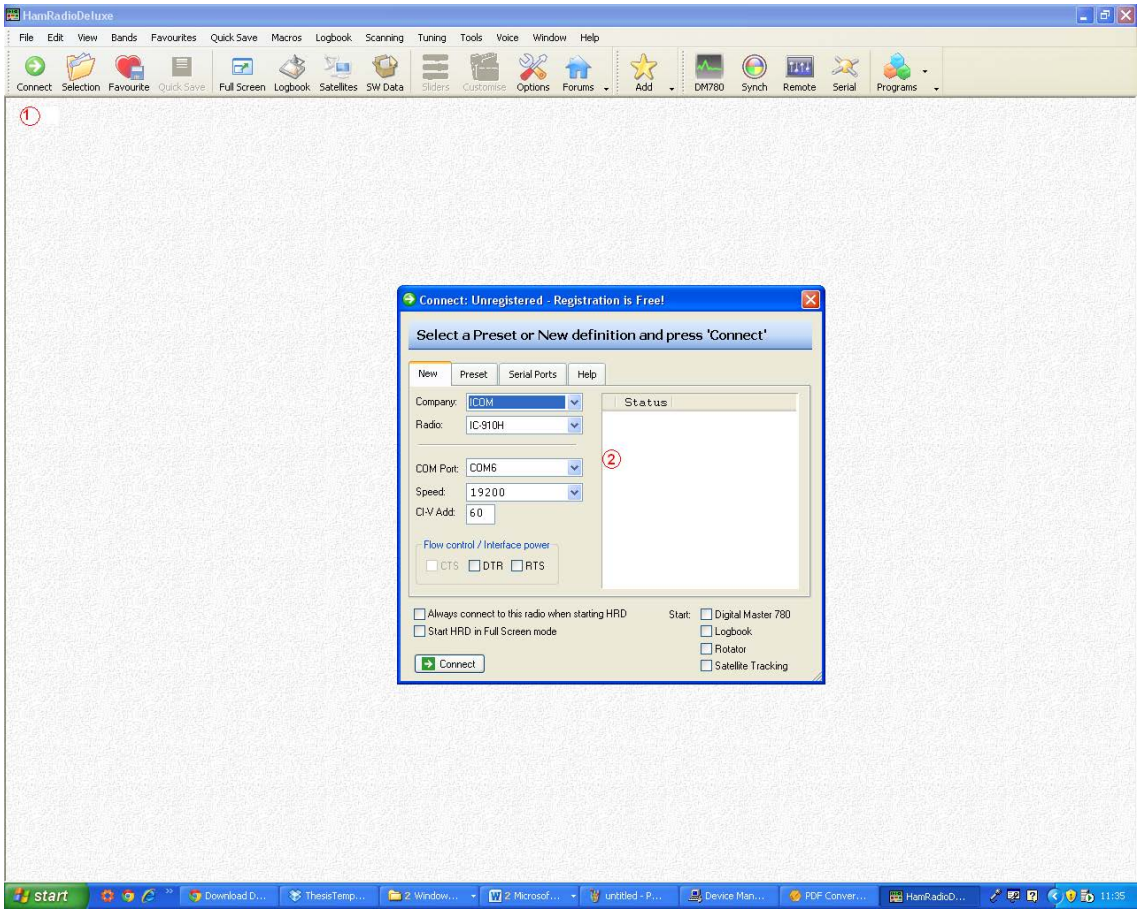
3.5mm plug into CAT port on IC-910H

■ Rear panel



Then connect the cable to the control computer and check out the **Port.** Current connected Port is **COM6**. Wherever, it should be checked again if re-plugged in a different port.

Configuration of the control software has to done manually. Once **Launch HamRadioDeluxe.exe** is executed, the control interface will appear and connection configuration is required.

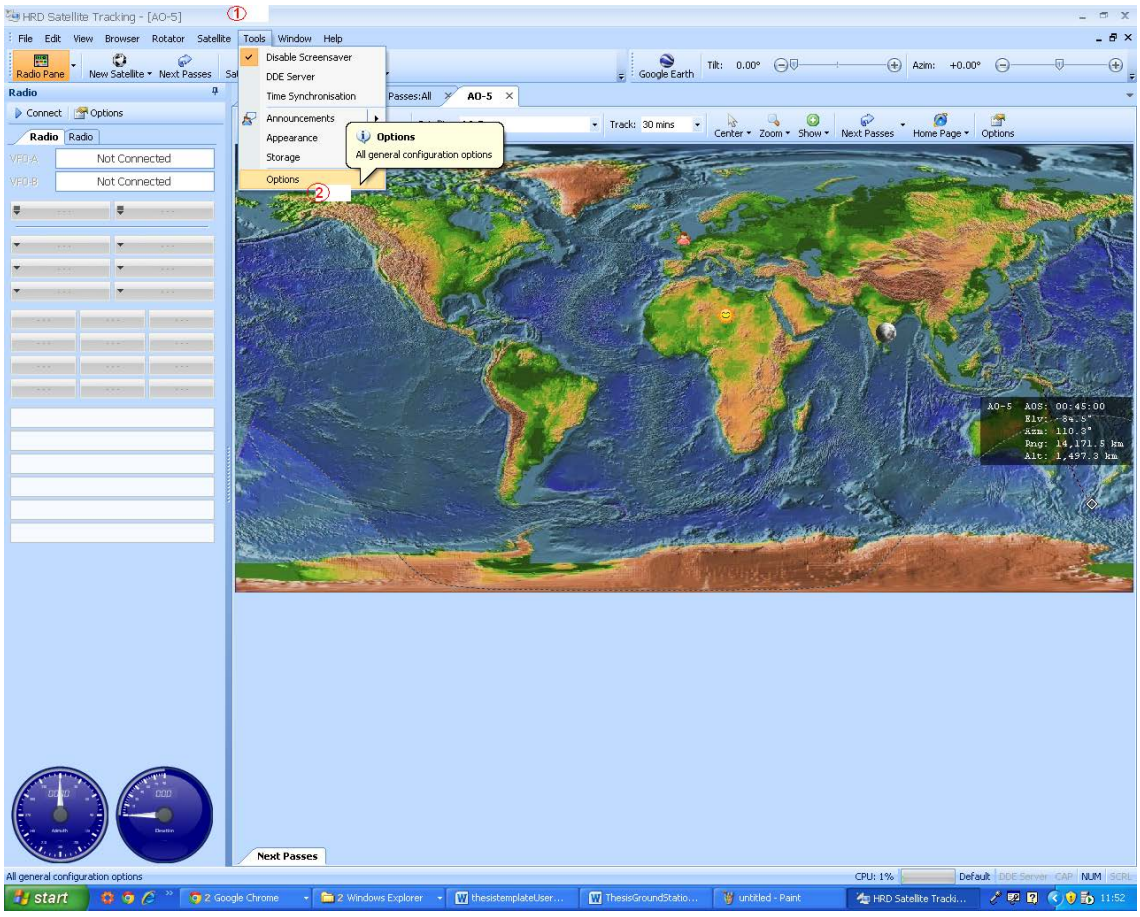

HamRadioDeluxe
File Edit View Bands Favourites Quick Save Macros Logbook Scanning Tuning Tools Voice Window Help
Connect Selection Favourite Quick Save Full Screen Logbook Satellites SW Data Sliders Customise Options Forums Add DM780 Synch Remote Serial Programs
①
Connect: Unregistered - Registration is Free!
Select a Preset or New definition and press 'Connect'
New Preset Serial Ports Help
Company: ICOM
Radio: IC-910H
COM Port: COM6
Speed: 19200
CI-V Add: 60
Flow control / Interface power
CTS DTR RTS
Status
②
Always connect to this radio when starting HRD
Start HRD in Full Screen mode
Start: Digital Master 780 Logbook Rotator Satellite Tracking
Connect
start

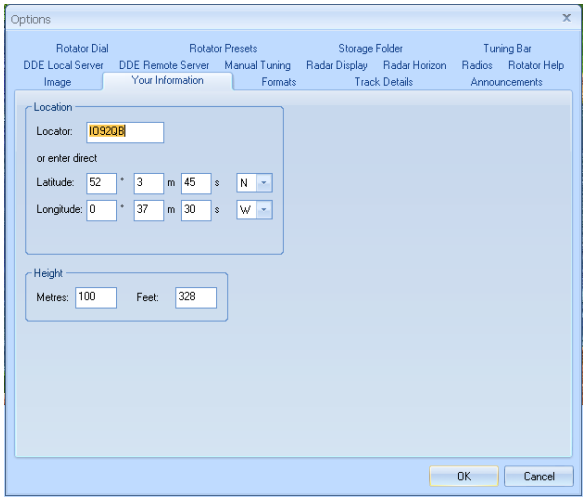
ICOM 910H to HRD Connection Setting	
Company	ICOM
Radio	IC-910H
COM-port	*check*
Speed	19200
CI-V	60

A.2.3 Ham Radio Deluxe Satellite Tracking

Before using HRD SatTrack to predict or track any satellite, antennas' location has to be specified to it. The GPS coordinates were measured on the roof where the mast is located. The longitude 0°37.69'W and latitude is 52°4.30'N.

Launch HRDSatTrack.exe > Tools > Options > Your Information





A.2.4 HRD Rotator connect to ERC-3D

ERC-3D works as interface between the control computer and rotator controller. Thus there is one USB cable to computer and one 7-core cable to rotator controller.

ERC-3D connect to computer

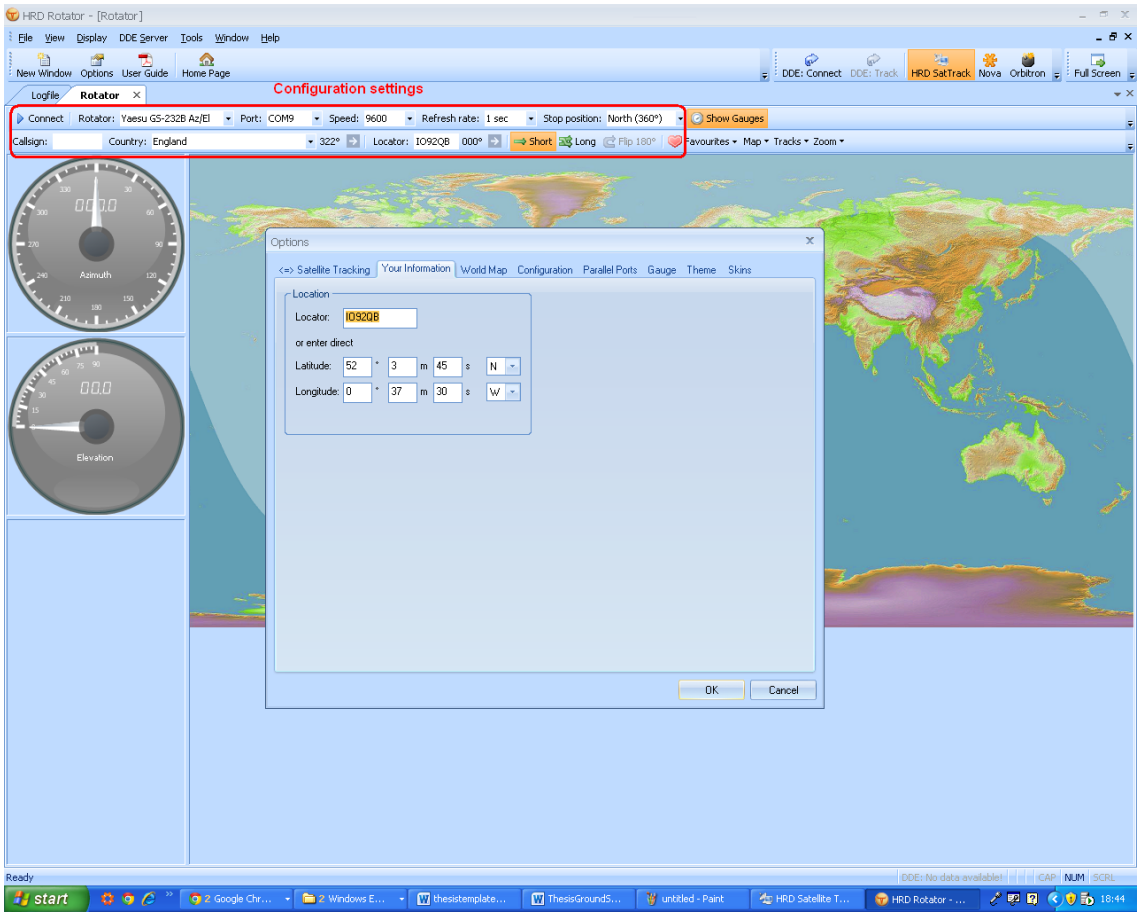
The actual cable to computer consists of two: one is the RS232 to 3.5mm phone plug cable and another one is RS232 to USB converter.

3.5mm stereo phone-jack to RS232 cable

StarTech.com RS232 to USB cable

Same as Satellite Tracking, Your Information has also to be specified in Rotator.

Launch HRDRotator.exe > Tools > Options > Your Information



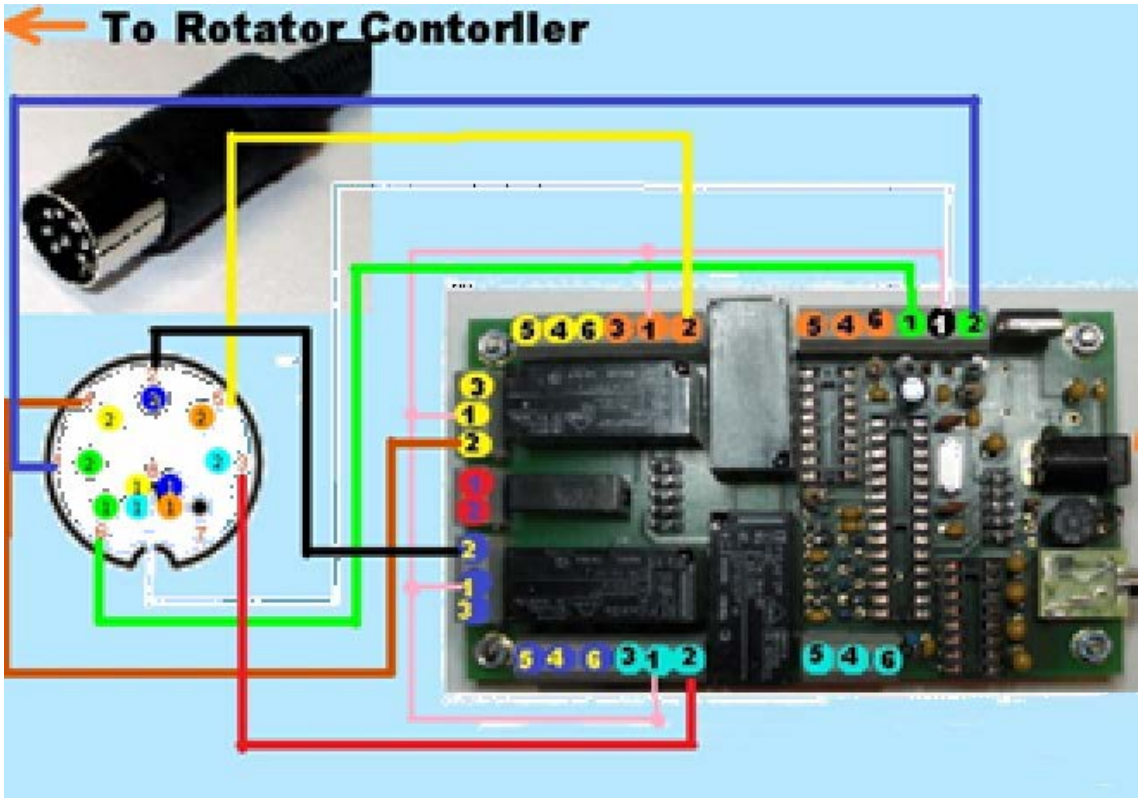
Configuration Settings:

ERC-3D to HRD Connection Setting	
Rotator	Yeasu GS-232B Az/El
Port	*check*
Speed	9600
Refresh Rate	1sec
Stop Position	North 360°
Call sign	CRANSAT
Country	England
Locator	IO92QB

ERC-3D Connect to Rotator Controller

The connection cable is a 7-core cable with 8-pin DIN connector (Pin 7 not in use). According to ERC-3D Instruction, wires up the 7-core cable.

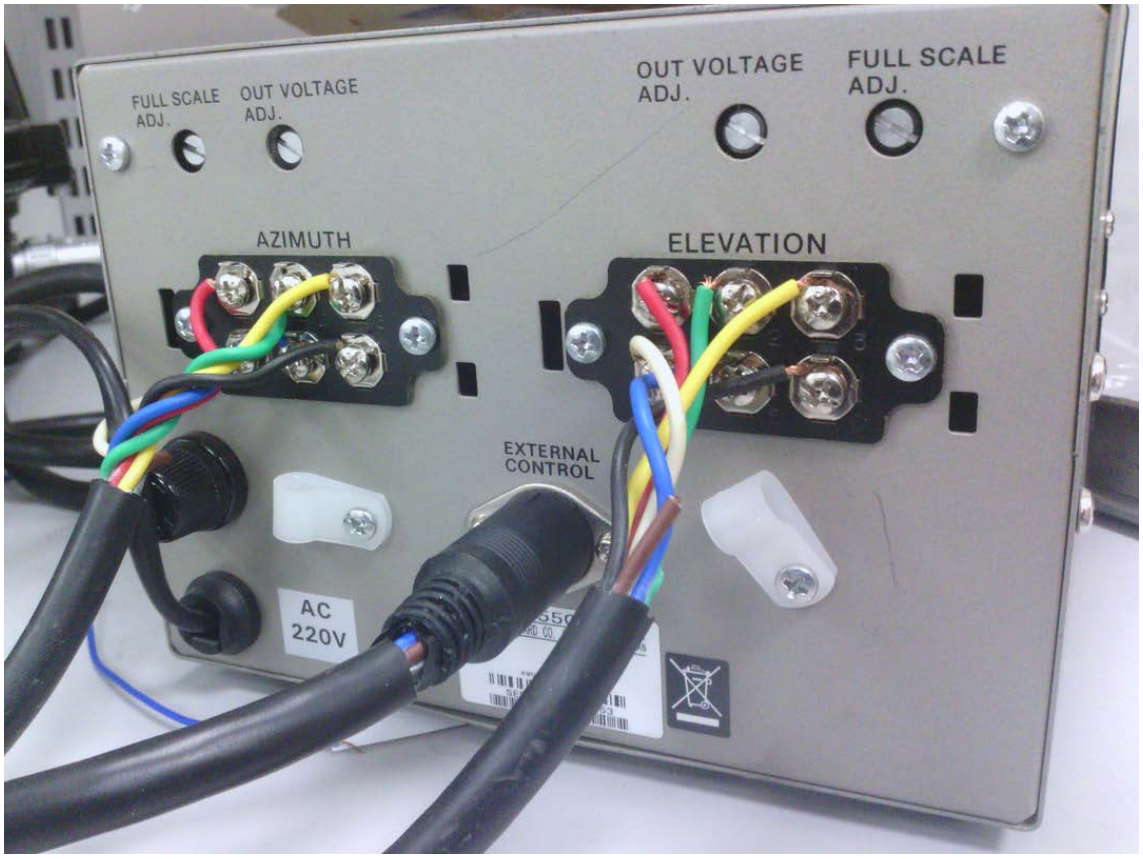
ERC-3D Terminals Connection		
ERC-3D PCB Terminals	**DIN Connector Pin no.**	**7-Core Cable Wire Colour**
1 1 1 1 1	8	White
1	6	Green
2	1	Blue
2	2	Black
2	4	Brown
2	3	Red
2	5	Yellow



Rotator Controller to Azimuth & Elevation motor

Yaesu G5500 Rotator Controller controls both Azimuth and Elevation motor through two 7-wire cable. The cable has one end connected to the Controller Screw Terminal and another end connected to motors with 7-pin DIN plugs. According to its Operating Manual, pin 7 is not used and the rest pins were connected to wires with different colour. Brown colour wire was assigned not to use.

Rotator Controller Cable Connection	
Pin No.	Wire Colour
1	Red
2	Green
3	Yellow
4	White
5	Blue
6	Black
7	Brown



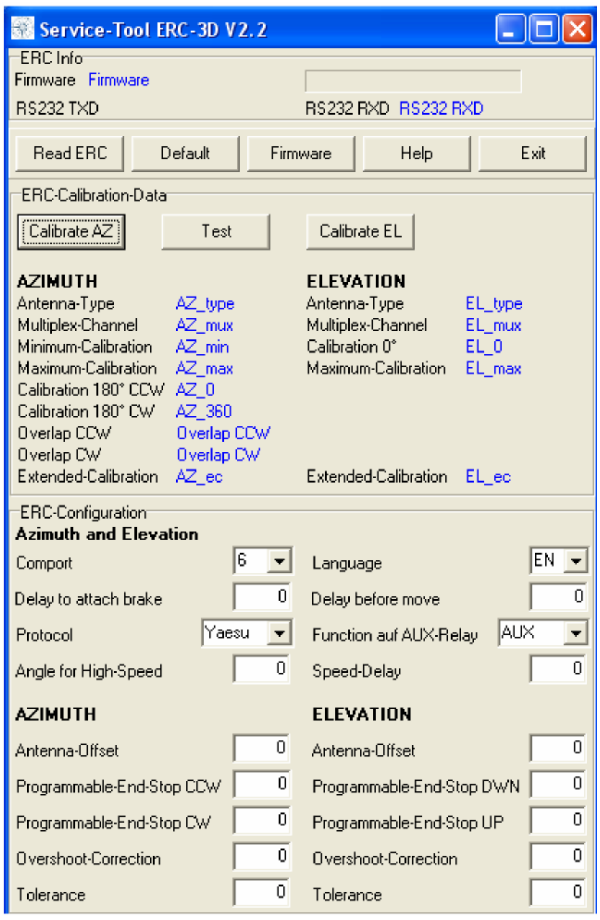
Cable connection of the Screw Terminals at the back of Rotator Controller.

ERC-3D Calibration with G5500 Rotator

ERC-3D has to be calibrated before it works properly with G5500. The essential of the calibration is to rescale the feedback voltage range of motors. Eventually the readings from ERC-3D, Rotator Controller and HRDRotator have to be same after calibration.

The following steps have to be followed for calibration:

Connect the ERC to the computer, power it and run ST3D_V22.exe (this program should be pre-installed from **setup ERC-3D_v22.exe)**. Check which COM **port** is used by the ERC using the **Device Manager**.

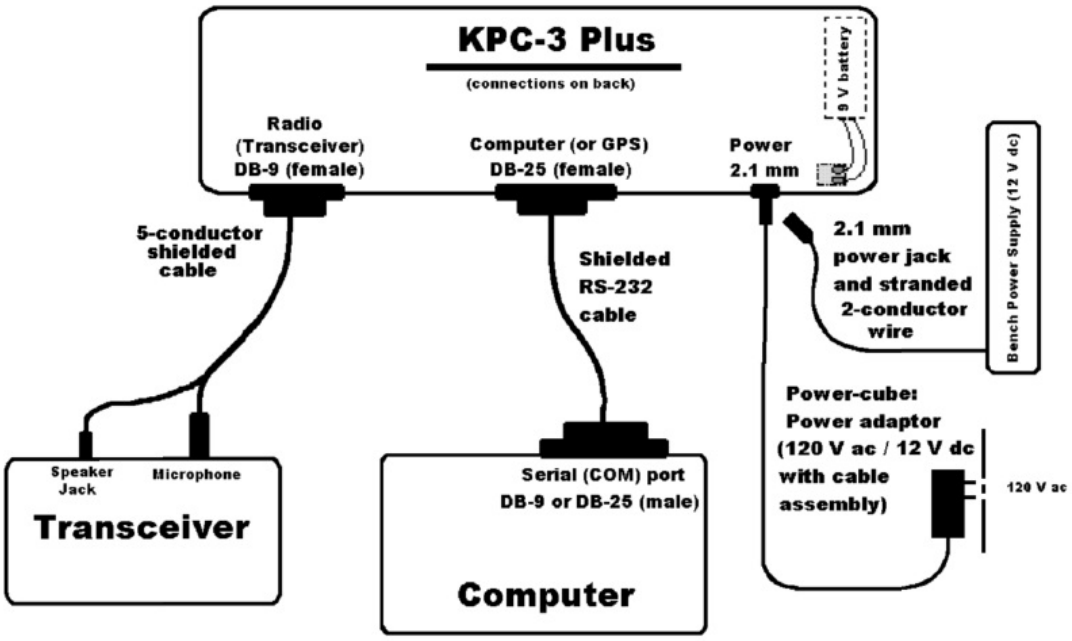


- Click on Calibrate Az to calibrate the azimuth
  - o Choose a south centred rotator
  - o There is no CCW overlap
  - o There is a CW overlap
  - o Then follow the instruction by manually (using the Yaesu Controller) putting the azimuth to the maximum CW position (450°), then CCW go to 360°, then CCW go to 0°.
  - o Then perform an extended calibration by calibrating every 30° from 0° to 360 °
- Then Click Calibrate El to calibrate the elevation
  - o Choose a 180° elevation rotator
  - o Follow the instruction by manually (using the Yaesu Controller) putting the elevation at 180°, then at 0°
  - o Then perform an extended calibration by calibration every 15° from 0° to 180°.
- Then make sure that the Antenna Offsets are both set to 0
- The programmable End Stops are to be set to 0
- The protocol must be set to GS232B

At the end of both steps, the ERC is calibrated. To test the calibration close the Service Tool ERC 3D and open Rotor Control 3D. By inputting target elevation and azimuth, and clicking on go AZ/EL the rotator should move towards those angles. Once the movement stops, all three displays (rotator, ERC and computer) should agree with each other on the position of the rotator

A.2.5 KPC3+ connect to HyperTerminal

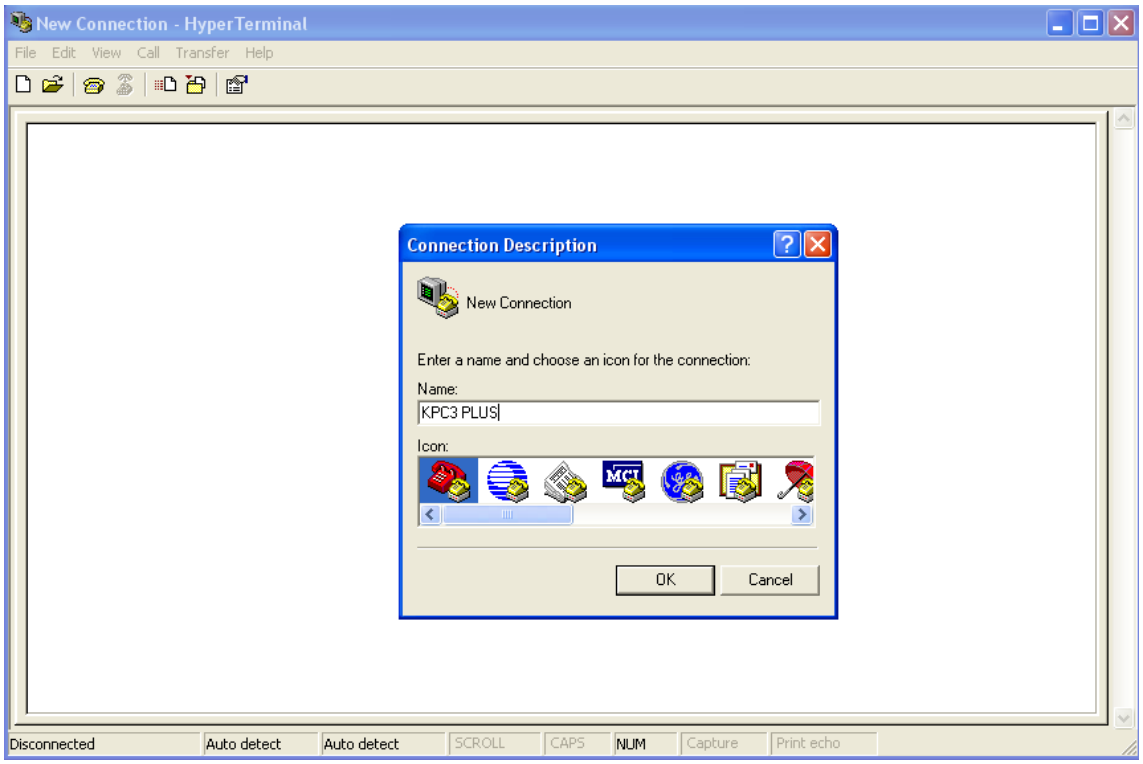
KPC3+ has two ports: DB-25 port is to the control computer and DB-9 is to the radio.



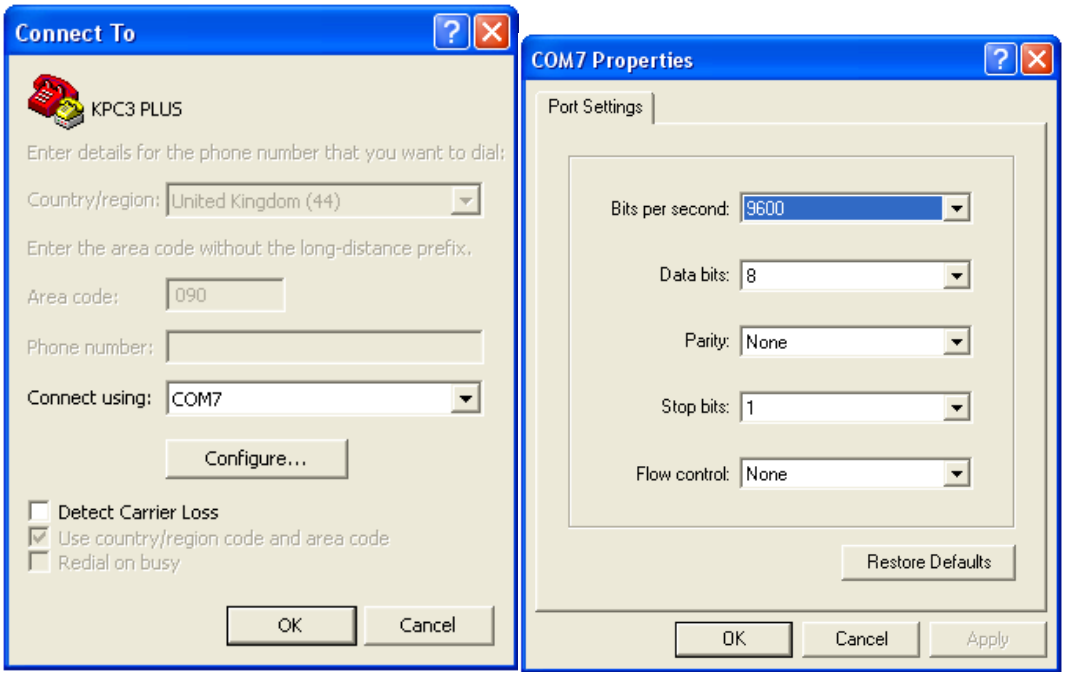
KPC3+ Connect to computer

First there is a DB-25 to DB-9 adapter and then connect to computer by StarTech.com USB cable. Once plugged in, the **Port** has to be checked out. Configuration with the control computer can be done from Hyper Terminal (Windows XP system has it)

Turn on KPC3+ and then run Hyper Terminal. First give a connection name and select an icon.

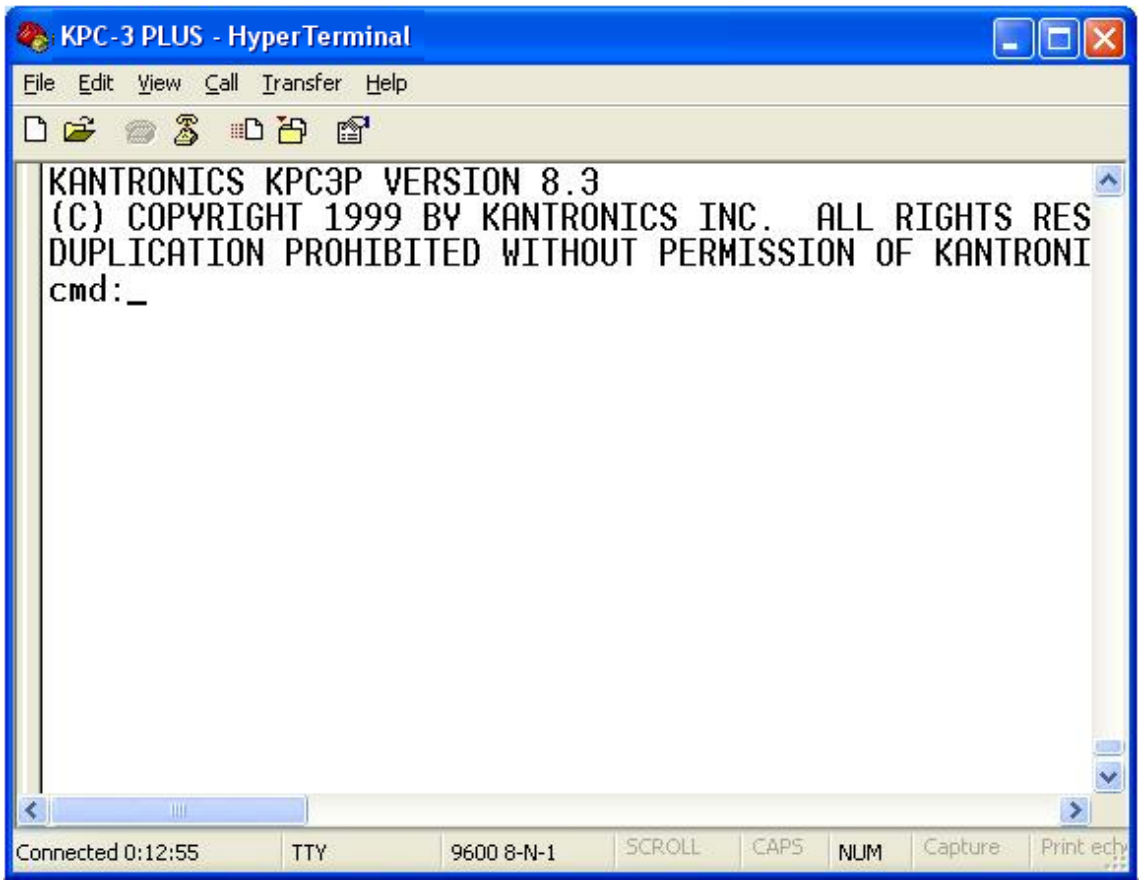


Then select the Port, here **COM7** is used. And **Configure**…



KPC-3+ to Hyper Terminal Connection Setting	
Bits per second	9600
Dtat bits	8
Parity	None
Stop bits	1
Flow control	Hardware

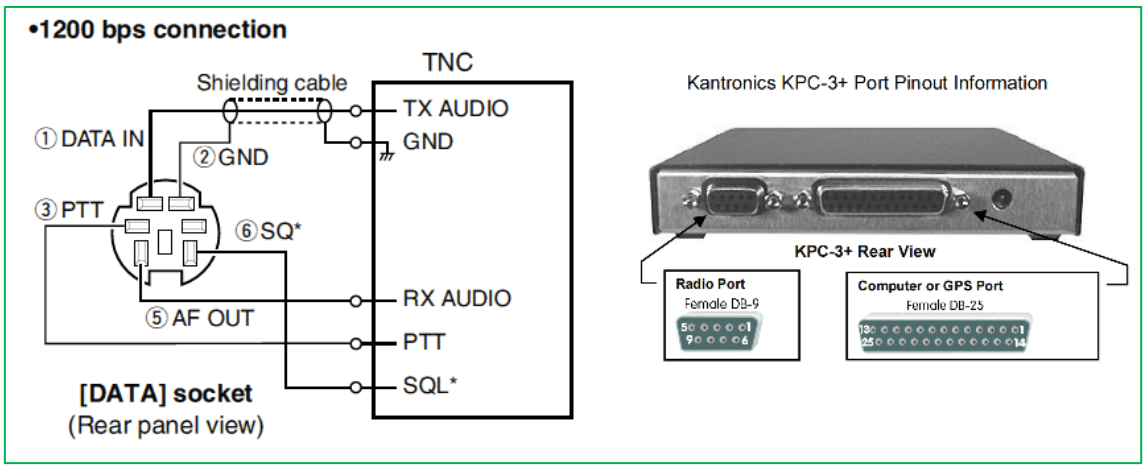
Once connected, in Hyper Terminal will show:



KPC3+ Connect to Radio IC-910H

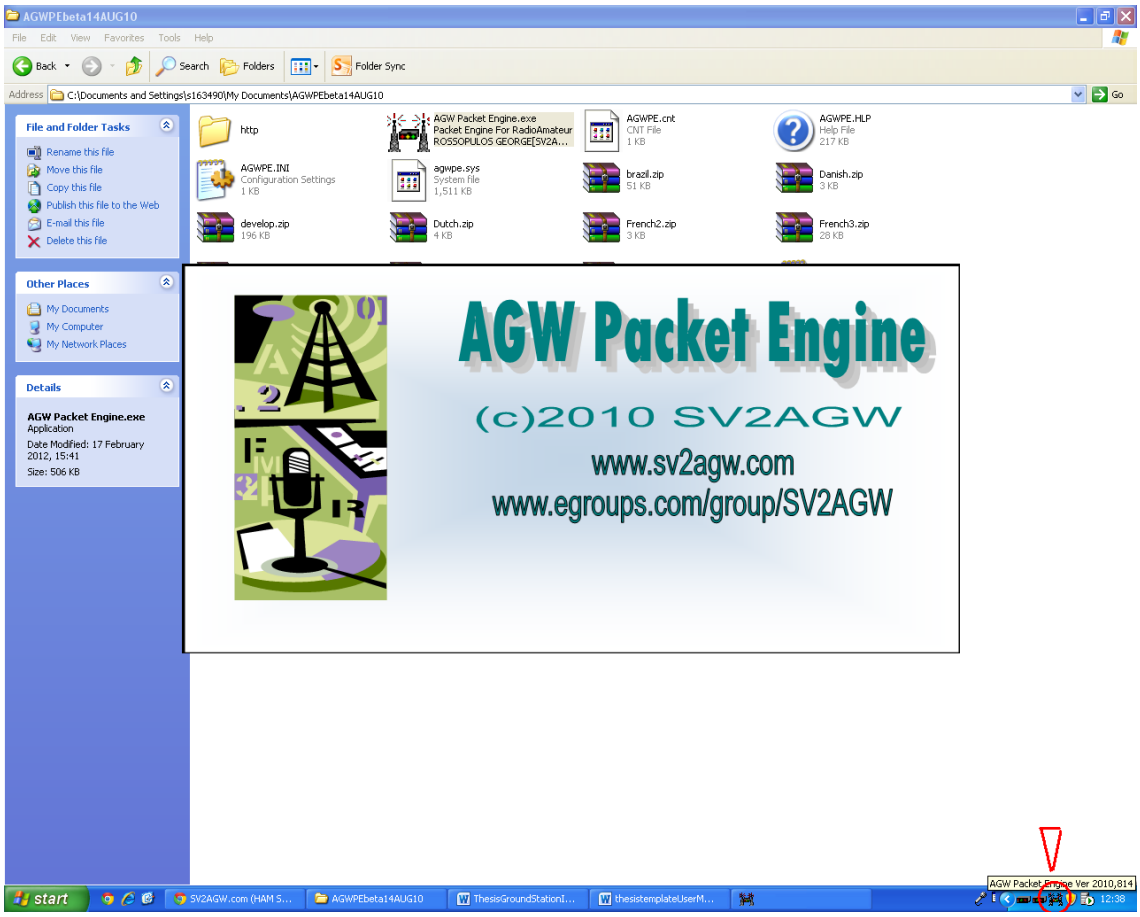
The connection between TNC and radio is a customised cable that one end with DB-9 male connector and another end is a 6-pin mini DIN plug.DB-9 has 9 pins of which four are wired to four of the 6-pin DIN connector.

pin no. of DB-9	connect	pin no. of 6-pin DIN connector
P.1 TXA Transmit audio (AFSK out)	⟷	P.1 DATA IN
P.3 PTT Push-to-Talk	⟷	P.3 PTT
P.5 RXA Receive audio (AFSK in)	⟷	P.5 AF OUT
P.6 GND Ground	⟷	P.2 GND

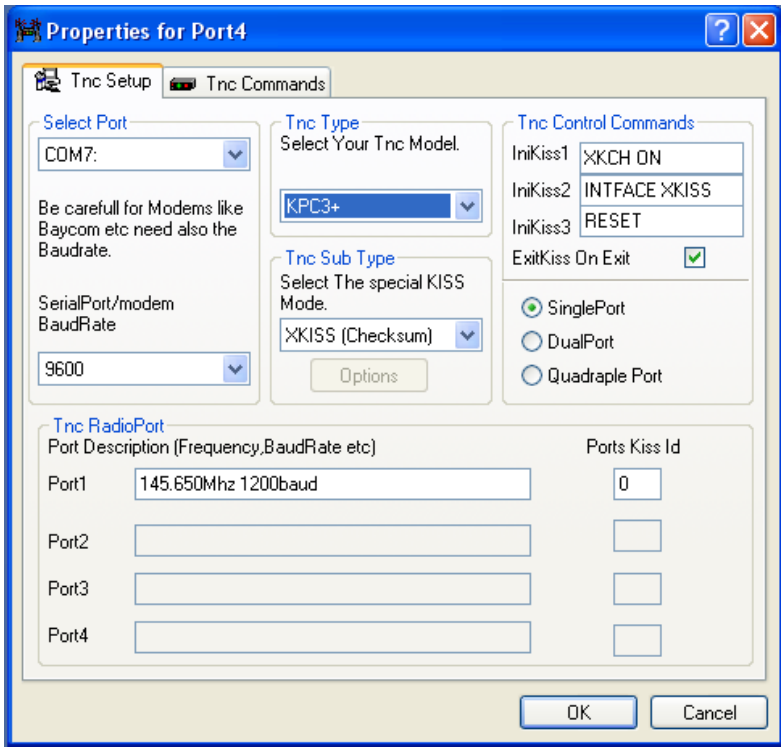


A.2.6 AGW Packet Engine

This software can be downloaded from http://www.sv2agw.com/ham/agwpe.htm and is free to use. Unzip the file then run **AGW Packet Engine.exe.**



Right click on the icon and select **Properties** > **New Port**

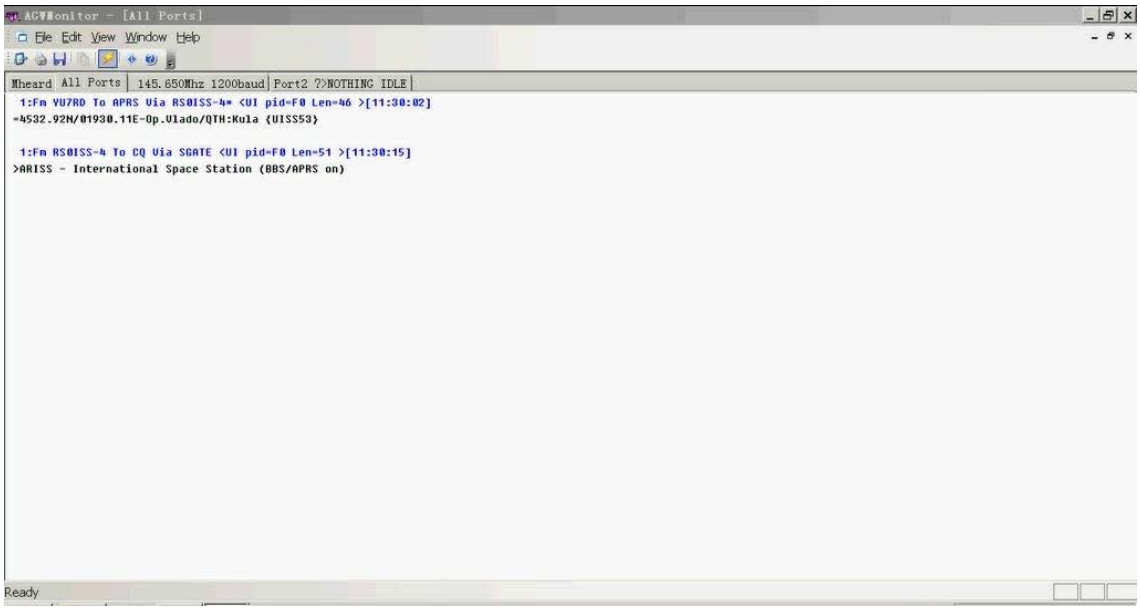


Again the communication **Port** should be checked and here is COM7, the configuration settings are:

AGW Packet Engine Properties	
Select Port	*check*
SerialPort/modem BaudRate	9600
Tnc RadioPort	fill in
Tnc Type	KPC3+

A.2.7 AGW Monitor

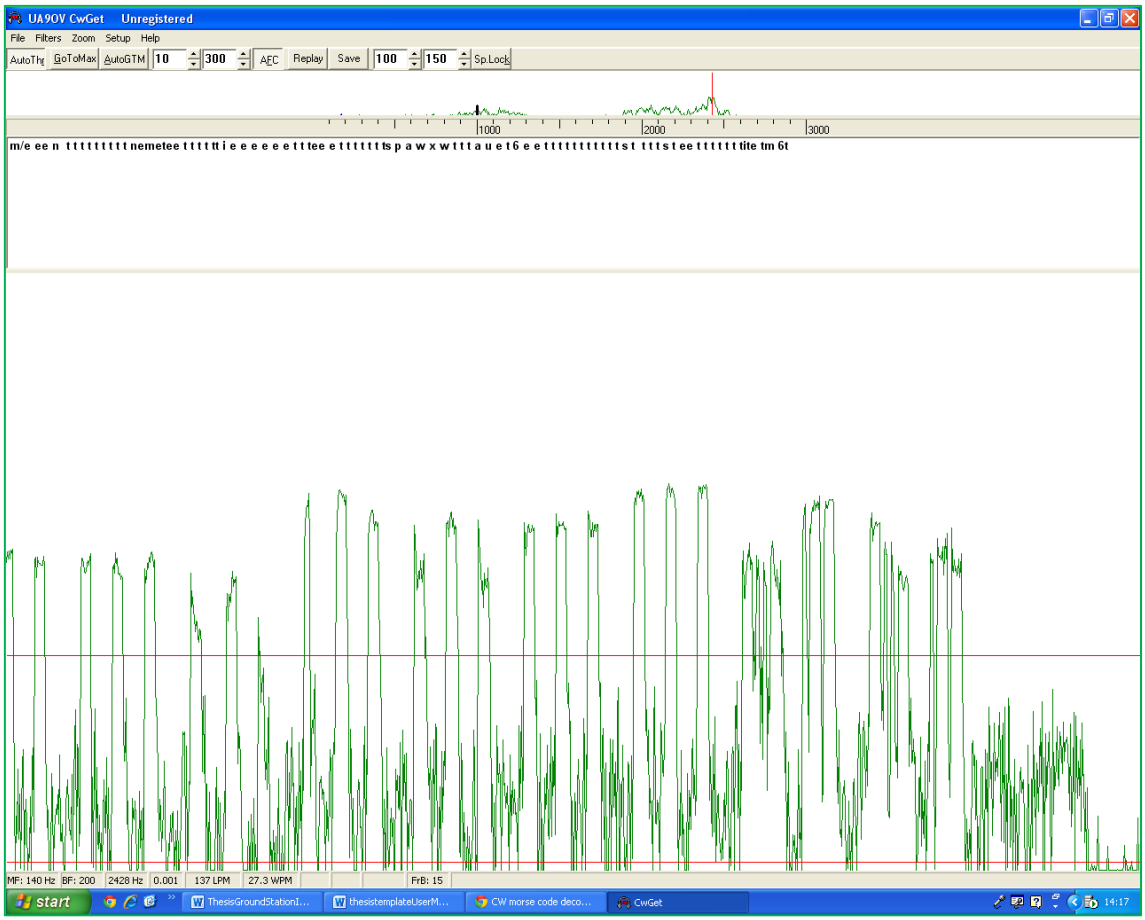
This software is compatible with AGW Packet engine. Once installed, then it is ready to use. All activities on the ports of TNC will be monitored and display the decoded message.



AGW Packet Pro is smart software that combines AGW Packet Engine and AGW Monitor. Moreover it can auto detect the Port when setting up the connection with TNC. However it charges $49 for registration.

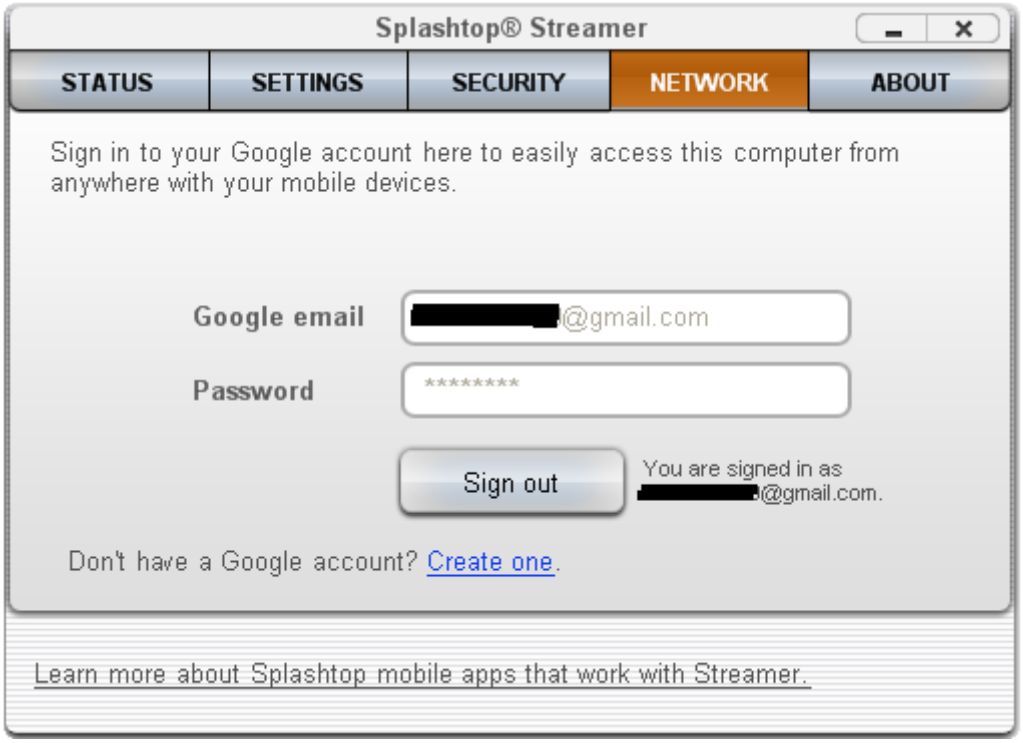
A.2.8 CW Get

This software is used to decode Morse Code beacons from satellite via soundcard. Signal input can be from a MIC or an audio cable directly from receiver. For detailed operation please refer to http://www.dxsoft.com/en/products/cwget/#bottom.

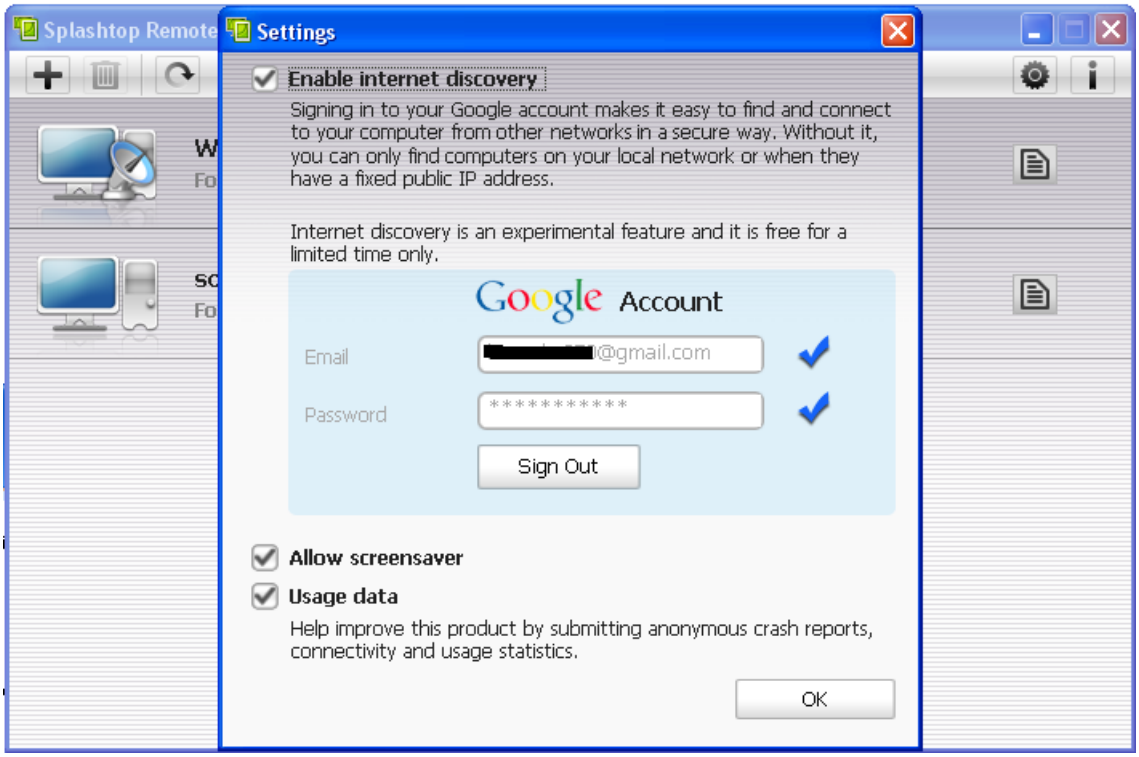


A.2.9 Desktop Remote Control

Two software have to be installed: Splashtop Remote Client and Splashtop Streamer. Splashtop Streamer is installed in the control computer. Sign in with an gmail account then the computer can be accessed anywhere when internet is available.



The computer must be installed with Splashtop Remote Client if used to access the control computer. The same gmail account should be used.

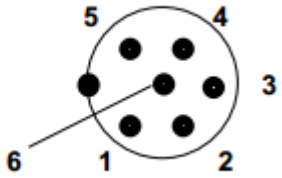

Splashtop Remote
Settings
Enable internet discovery
Signing in to your Google account makes it easy to find and connect to your computer from other networks in a secure way. Without it, you can only find computers on your local network or when they have a fixed public IP address.
Internet discovery is an experimental feature and it is free for a limited time only.
Google Account
Email
[redacted]@gmail.com
Password
****
Sign Out
Allow screensaver
Usage data
Help improve this product by submitting anonymous crash reports, connectivity and usage statistics.
OK

These software can be downloaded from http://www.splashtop.com/.

A.2.10 Wimo Polarisation Switches

No.18080 is for VHF band and No. 18082 is for UHF band. All of them have 4 polarisation options: Vertical, Horizontal, RHCP and LHCP. The control principle is feeding the signal to antenna with different length of cable with different impedance. The switching function is implemented with several 12V relays. If no voltage applied, the antenna is **Vertical** polarised. Conncetion to these switches is a 4-core cable with 6-pin MIC connector.

6-pin MIC control plug:
- Pin 1: circular right
- Pin 2: circular left
- Pin 3: n.c.
- Pin 4: GND
- Pin 5: horizontal
- Pin 6: n.c.



II. Connecting the switch to our antennas

X-Quad:

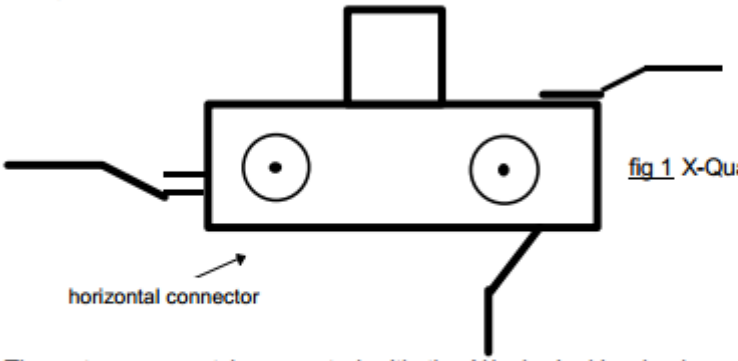


fig 1 X-Quad jacks

The antennas must be mounted with the N-jacks looking backward. The connector box must be horizontal. See figure 1.

2m: Both cables between switch and antenna must have the same length!
70cm: The cable to the horizontal plane must be longer (L/4 x velocity factor, i.e. 172mm x 0,66 = 112mm, for a cable with PE-insulation) than the cable used for the vertical plane.

A.2.11 Arduino Webserver Switches Controller

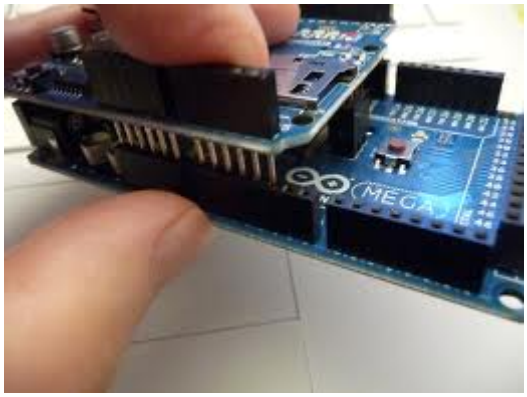
This webserver consists of:

- Arduino ATMEGA 2560
- Arduino Ethernet Shield (poe)
- SainSmart 8-Channel 5V Solid State Relay Module Board

- 4-Channel 5V Relay Module Expansion unit
- 9g Mini Micro Light Weight Servo

Assembly and Connection & Pin Assignment

Stack the Ethernet Shield on ATMEGA2560 with right orientation.



Arduino Mega2560 Pins Assignment	
Pin No.	**Assignment**
2	VHF Horizontal
3	VHF RHCP
4	VHF LHCP
5	UHF Horizontal
6	UHF RHCP
7	UHF LHCP
8	Power Switch 1
9	Servo
14(A0)	Power Switch 2
15(A1)	Power Switch 3
16(A2)	Power Switch 4
17(A3)	Power Switch 5
18(A4)	Power Switch 6
19(A5)	Power Switch 7

Uploading Program to Arduino Board

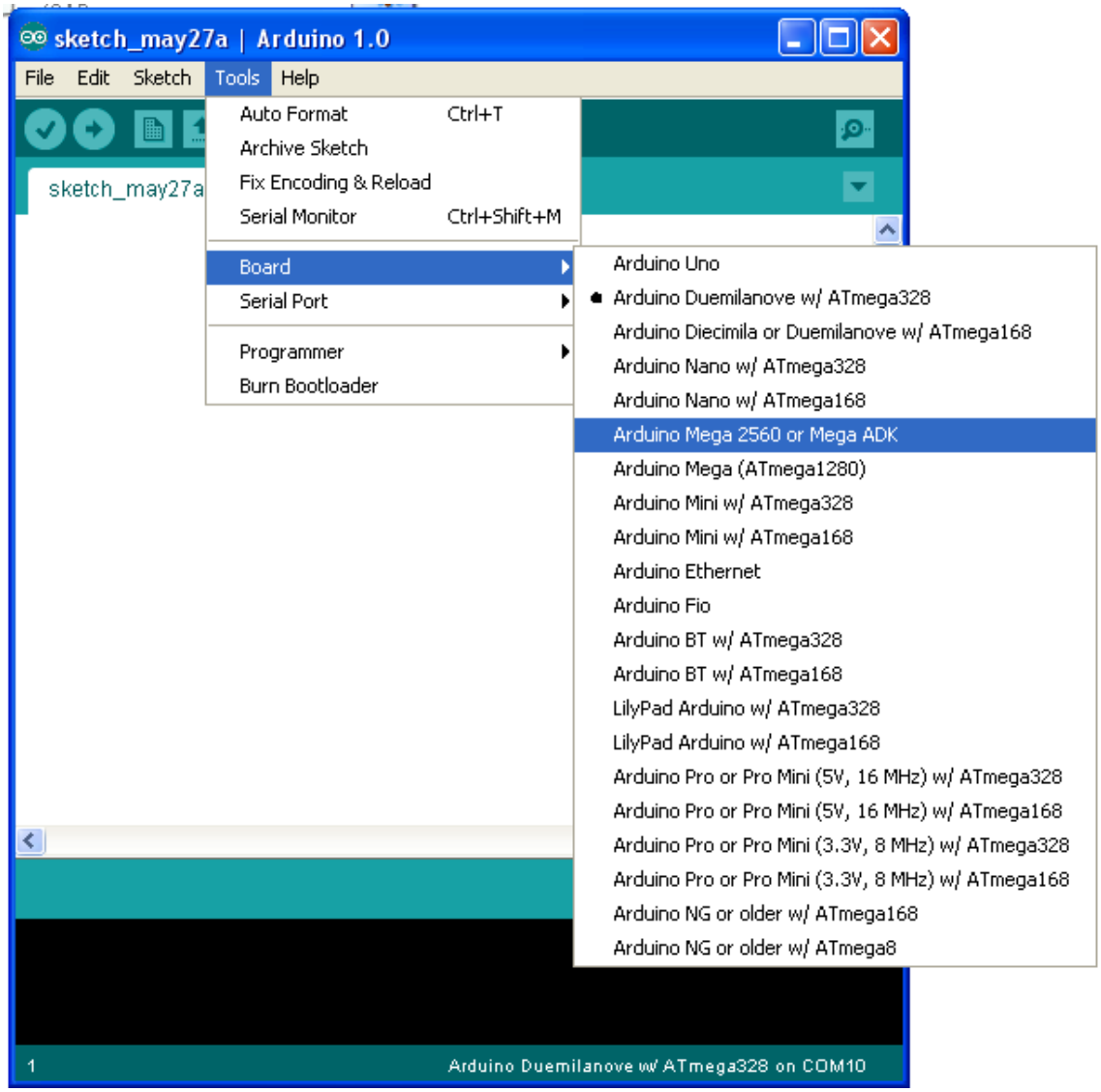
The IDE software used is **arduino-1.0-windows** which can be downloaded from http://arduino.cc/en/Main/Software.

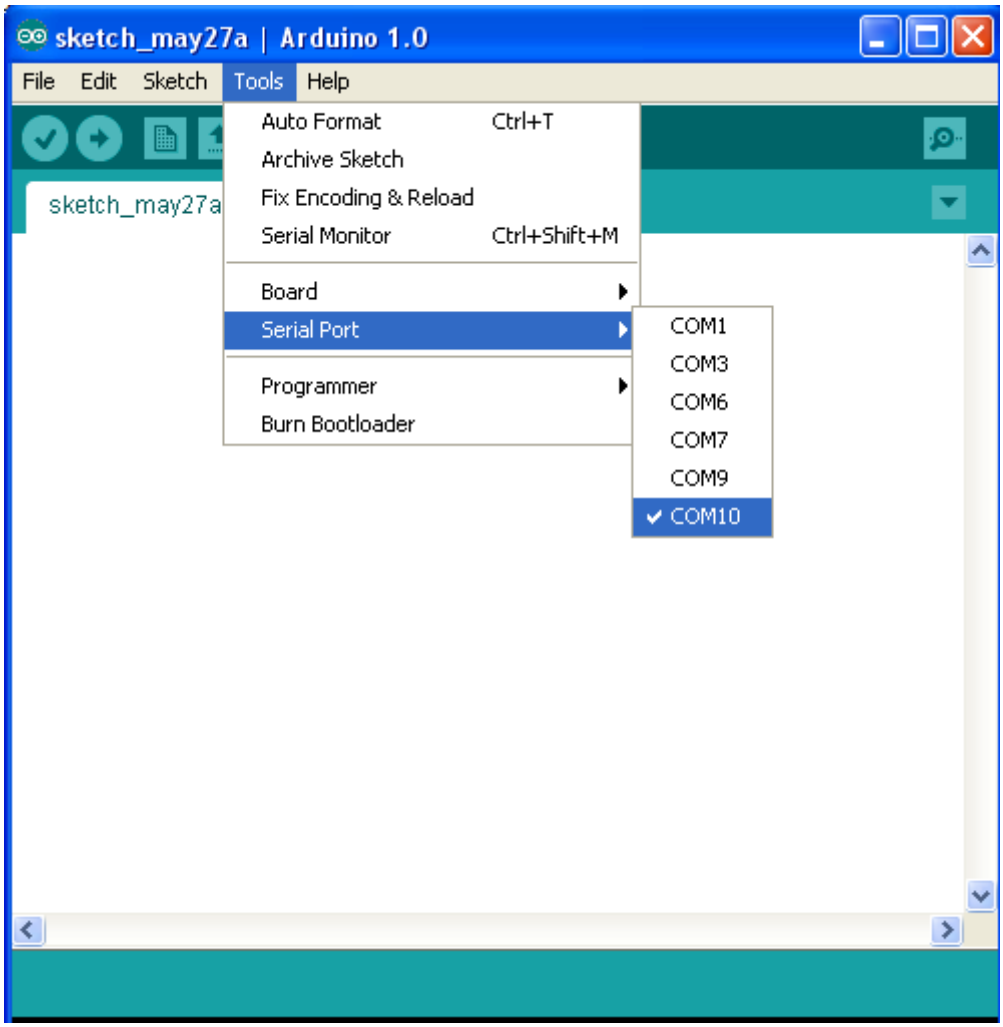
Unzip the file and run **arduino.exe.** Connect the board to the control computer by an USB cable. Again check out the **Port.**

Select the Serial Port and Board:

Tools > Board > Arduino Mega 2560or Mega ADK

Tools > Serial Port > COM10


sketch_may27a | Arduino 1.0
File Edit Sketch Tools Help
Auto Format Ctrl+T
Archive Sketch
Fix Encoding & Reload
Serial Monitor Ctrl+Shift+M
Board
Serial Port
Programmer
Burn Bootloader
Arduino Uno
Arduino Duemilanove w/ ATmega328
Arduino Diecimila or Duemilanove w/ ATmega168
Arduino Nano w/ ATmega328
Arduino Nano w/ ATmega168
Arduino Mega 2560 or Mega ADK
Arduino Mega (ATmega1280)
Arduino Mini w/ ATmega328
Arduino Mini w/ ATmega168
Arduino Ethernet
Arduino Fio
Arduino BT w/ ATmega328
Arduino BT w/ ATmega168
LilyPad Arduino w/ ATmega328
LilyPad Arduino w/ ATmega168
Arduino Pro or Pro Mini (5V, 16 MHz) w/ ATmega328
Arduino Pro or Pro Mini (5V, 16 MHz) w/ ATmega168
Arduino Pro or Pro Mini (3.3V, 8 MHz) w/ ATmega328
Arduino Pro or Pro Mini (3.3V, 8 MHz) w/ ATmega168
Arduino NG or older w/ ATmega168
Arduino NG or older w/ ATmega8
1
Arduino Duemilanove w/ ATmega328 on COM10



Open the program **WebserverController.ino** which is called sketch in Arduino.

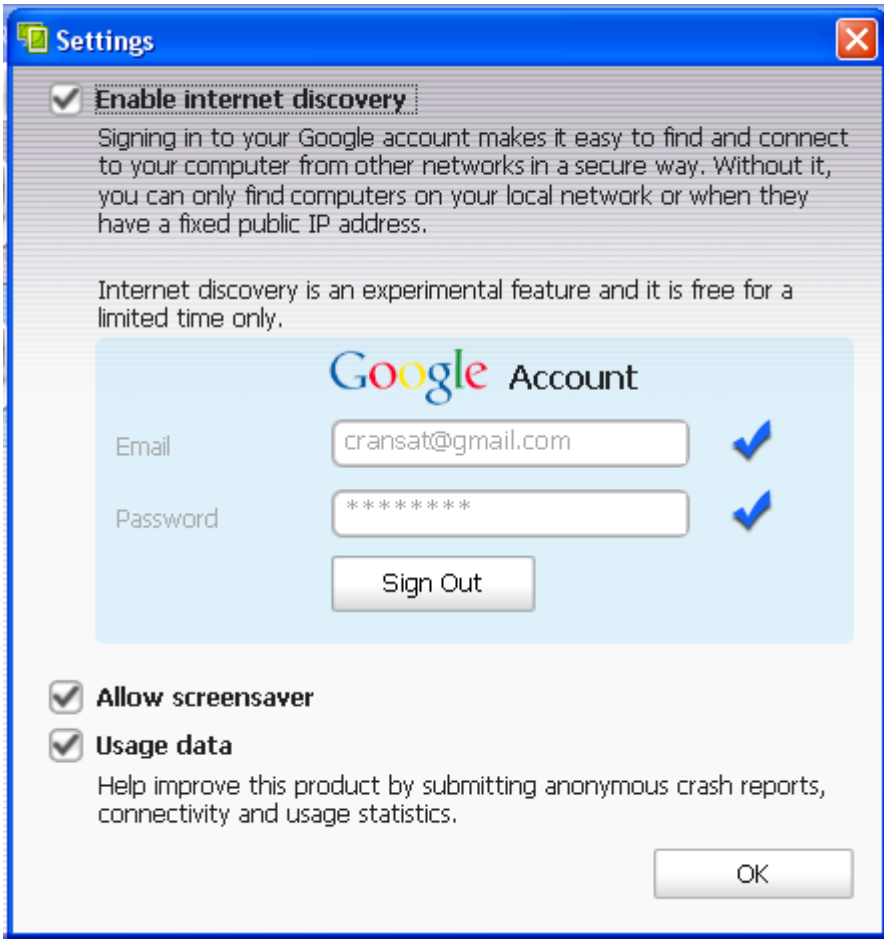
Click to upload the sketch. This process will take a while, as the program will be first verified then uploading. When finished, it will show " uploading done" at the bottom.

A.3 Operation Procedure

The following procedure has to be followed for remote accessing Cranfield Ground Station.

A.3.1 Step1 Run Splashtop Remote Client

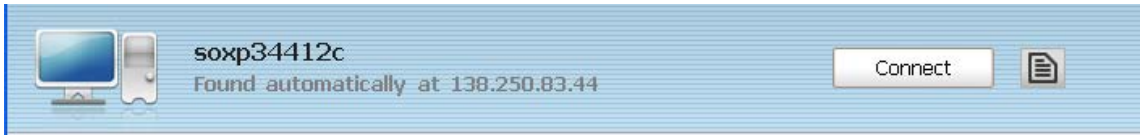
If this program is just installed, then complete the settings


Settings
Enable internet discovery
Signing in to your Google account makes it easy to find and connect to your computer from other networks in a secure way. Without it, you can only find computers on your local network or when they have a fixed public IP address.
Internet discovery is an experimental feature and it is free for a limited time only.
Google Account
Email
cransat@gmail.com
Password
****
Sign Out
Allow screensaver
Usage data
Help improve this product by submitting anonymous crash reports, connectivity and usage statistics.
OK

Email: cransat@gmail.com

Password: *******

Then connect the control computer: name **soxp34412c**



Call **Cransat** on Skype, it will be automatically answered.

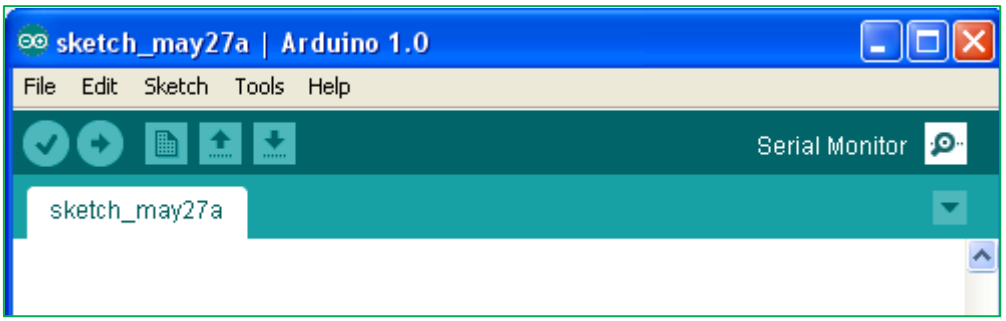
A.3.2 Step2. Access Webserver Controller

Open Google Chrome, and type IP address: **138.250.83.202** into address then Enter.

In case the webpage can not be found, probably because of the IP address has changed (DHCP). Therefore new IP has to be find out.

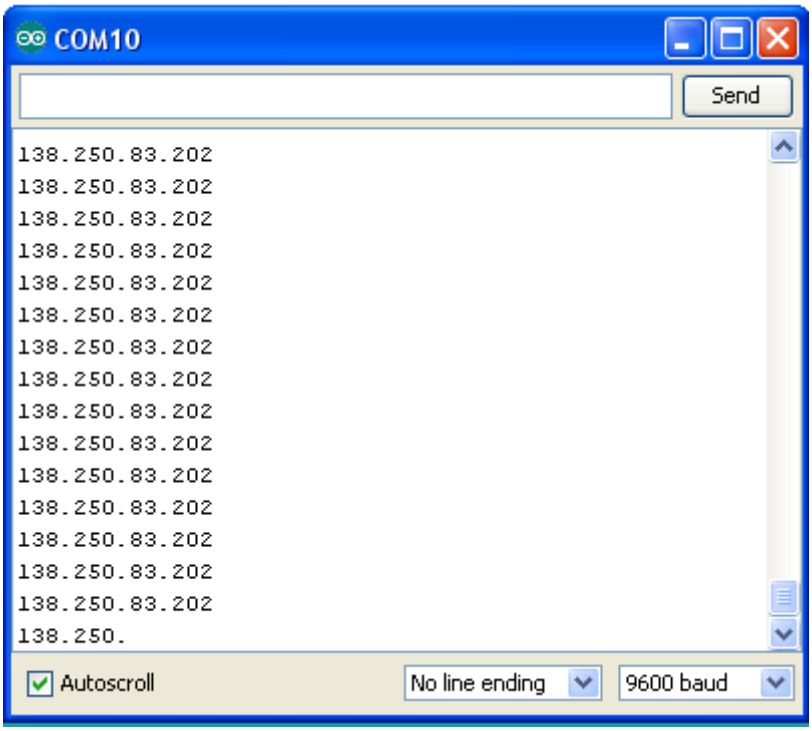
Click the icon on desktop

to run the Arduino IDE. And then open ***Serial Monitor*** *as shown below*



Or can be open through: ***Tools*** *>* ***Serial Monitor***

Wait for a few seconds then the IP will print out. If the display is garbled code, then close the Serial Monitor and re-open again. Close Serial Monitor and Arduino IDE!

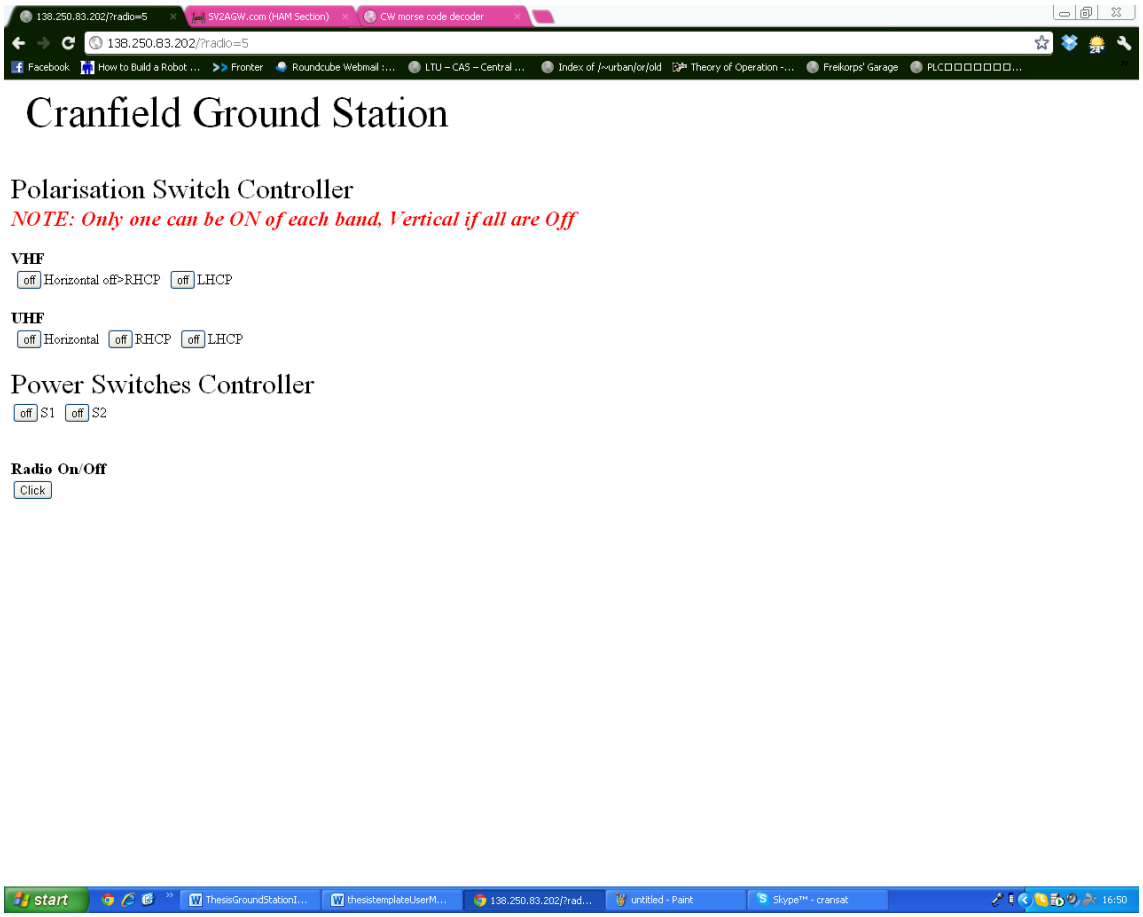


After loading the web browser successfully, switch on the polarisation switches and then the power for each device.

Note:

1 Only one switch of the polarisation switch can be on for each band. If two are on then there is no connection to antenna.

2. you should hear the sound from radio when it is turned on.

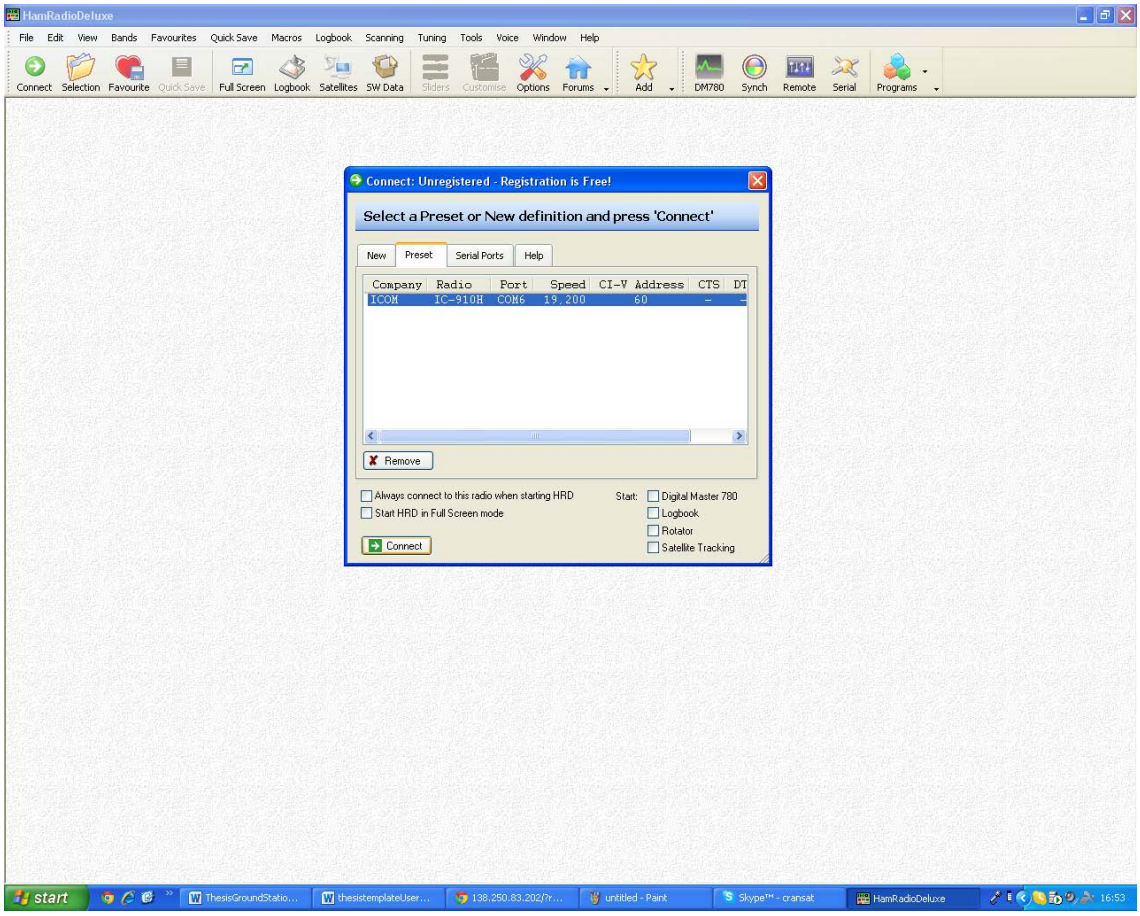


A.3.3 Step3 Run Ham Radio Deluxe

Click the icon

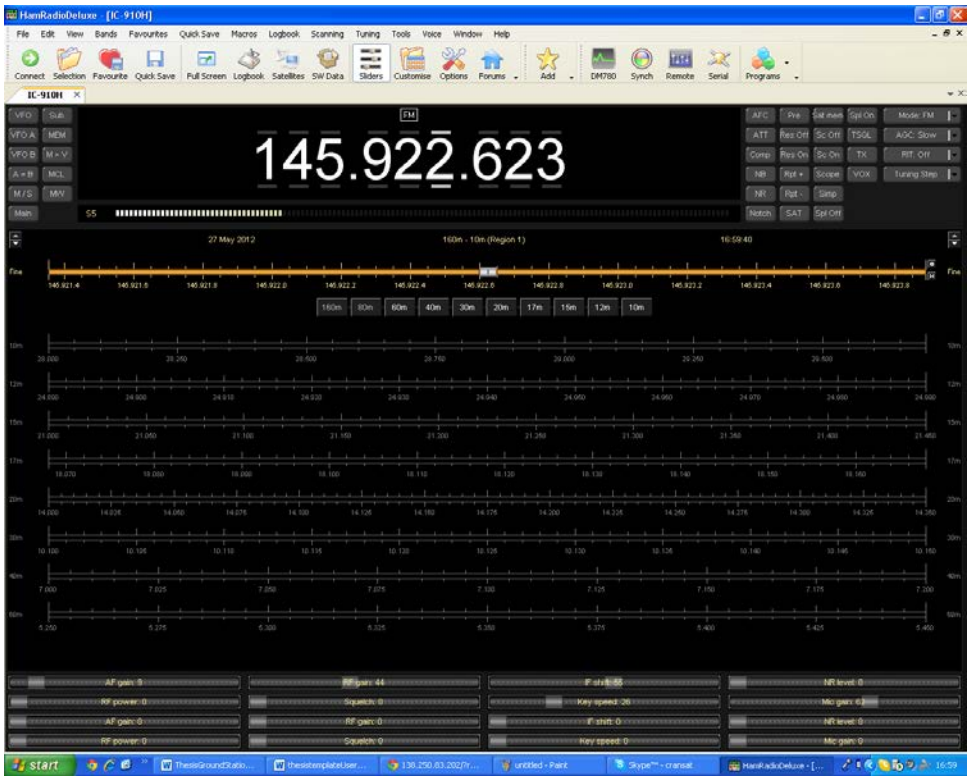
on the desktop and then connect the radio.

*Note: please remember to check the **Port** and reconfigure the connection once the USB cable is re-plugged to different port.*

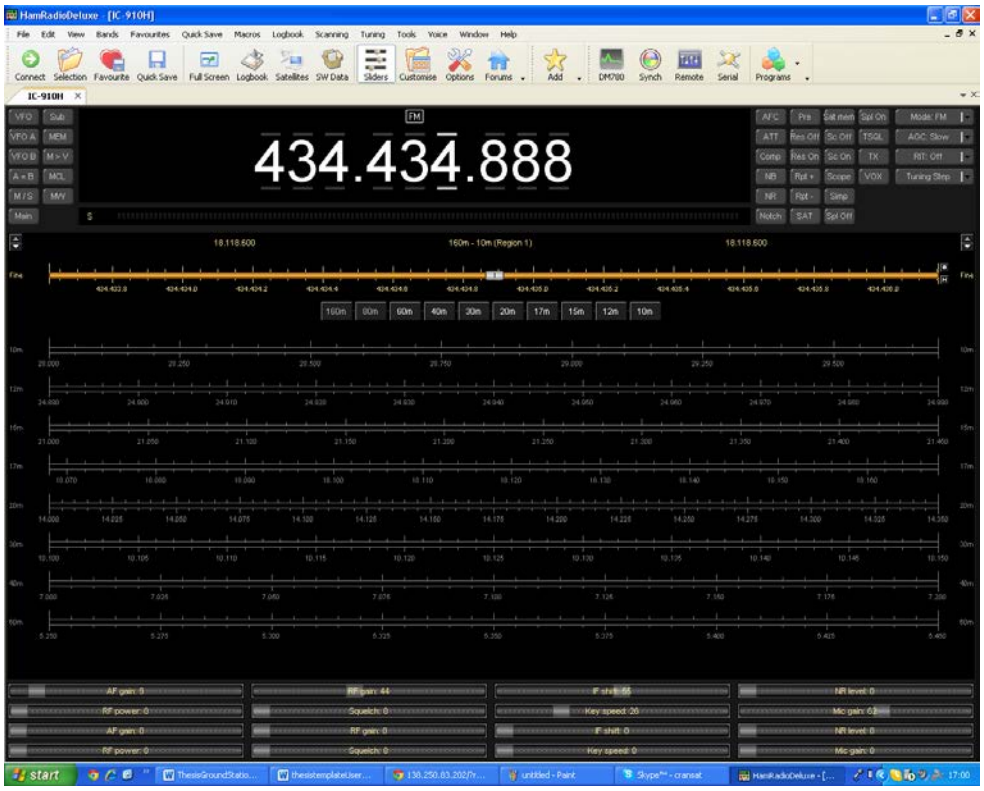

HamRadioDeluxe
File Edit View Bands Favourites Quick Save Macros Logbook Scanning Tuning Tools Voice Window Help
Connect Selection Favourite Quick Save Full Screen Logbook Satellites SW Data Sliders Customise Options Forums Add DM780 Synch Remote Serial Programs
Connect: Unregistered - Registration is Free!
Select a Preset or New definition and press 'Connect'
New Preset Serial Ports Help
Company Radio Port Speed CI-V Address CTS DT
ICOM IC-910H COM6 19,200 60 – –
Remove
Always connect to this radio when starting HRD
Start HRD in Full Screen mode
Start: Digital Master 780 Logbook Rotator Satellite Tracking
Connect
start
ThesisGroundStatio...
thesistemplateUser...
138.250.83.202/?r...
untitled - Paint
Skype™ - cransat
HamRadioDeluxe
16:53

Once connected, first to check the signal strength if it is normal.

If the signal strength is zero or near to zero, then the antenna is not connected or the cable is broken. First go back **Step2** and check the polarisation switches if they are on.



Connected to antenna



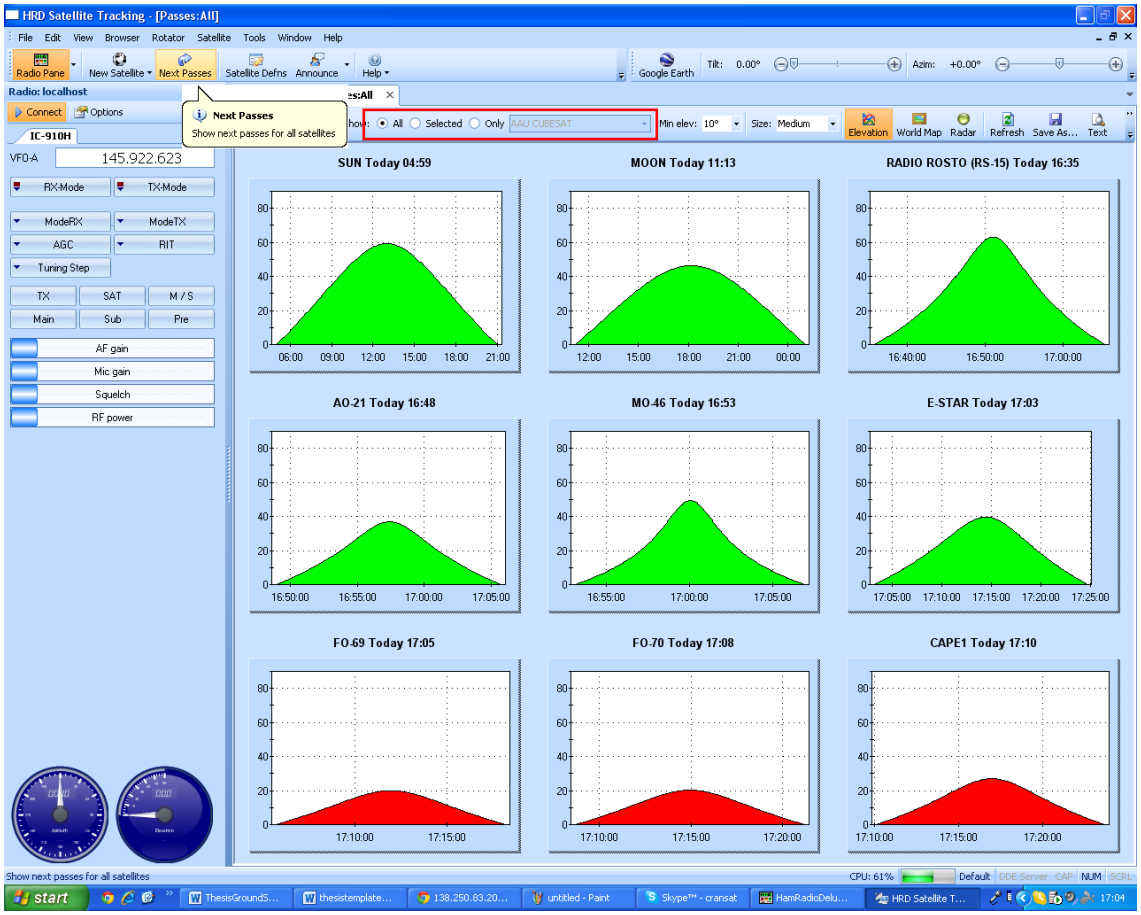
Non- connected to antenna

A.3.4 Step4 HRD Satellite Tracking

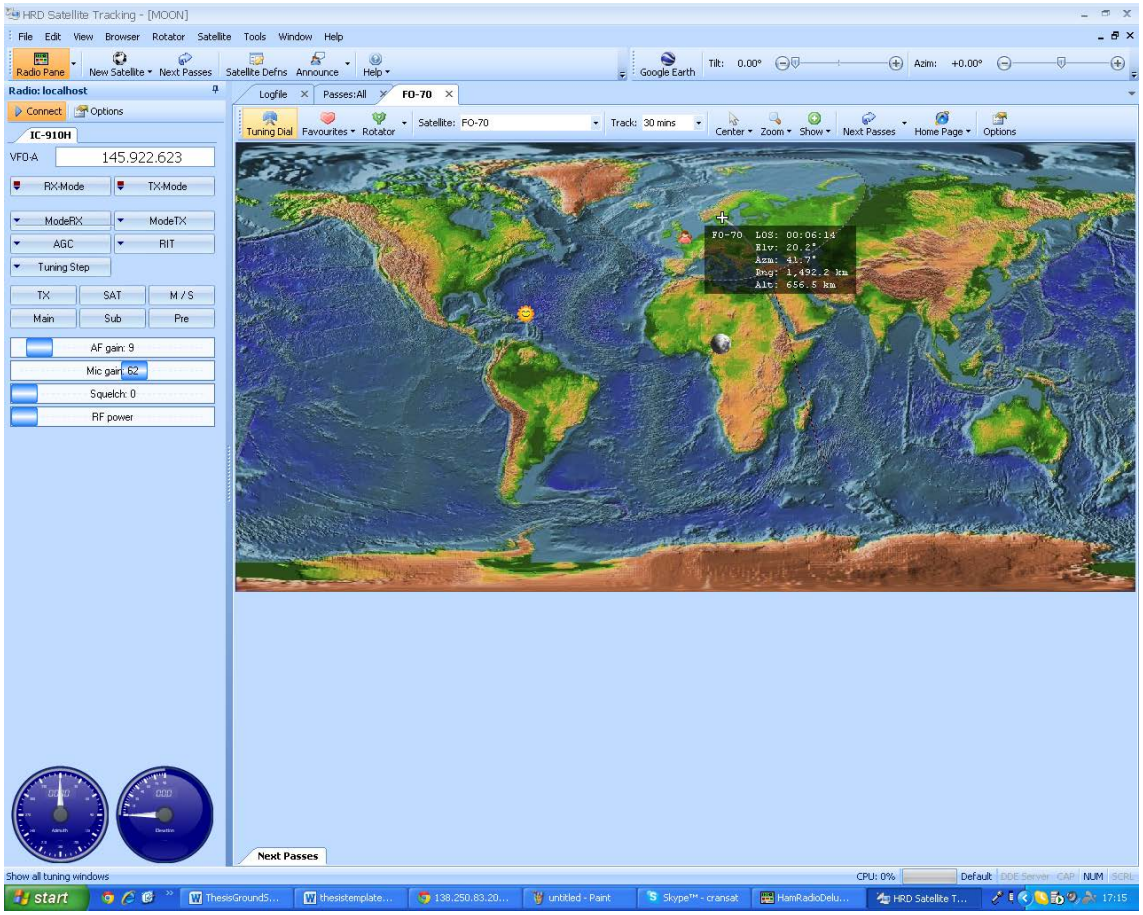
Click the icon

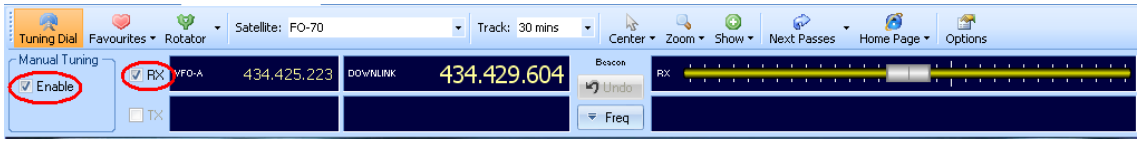
to start Satellite Tracker.

Next Passes: to predict the incoming passages of satellite. It has options for **All**, **Selected** or **Only.** To check the detail pass of some satellite, then take **Only.** Remember AOS and LOS for the operation.



Next Satellite: take one satellite from the list for the operation. Then click **Tuning Dial** and take **Enable** and **RX**

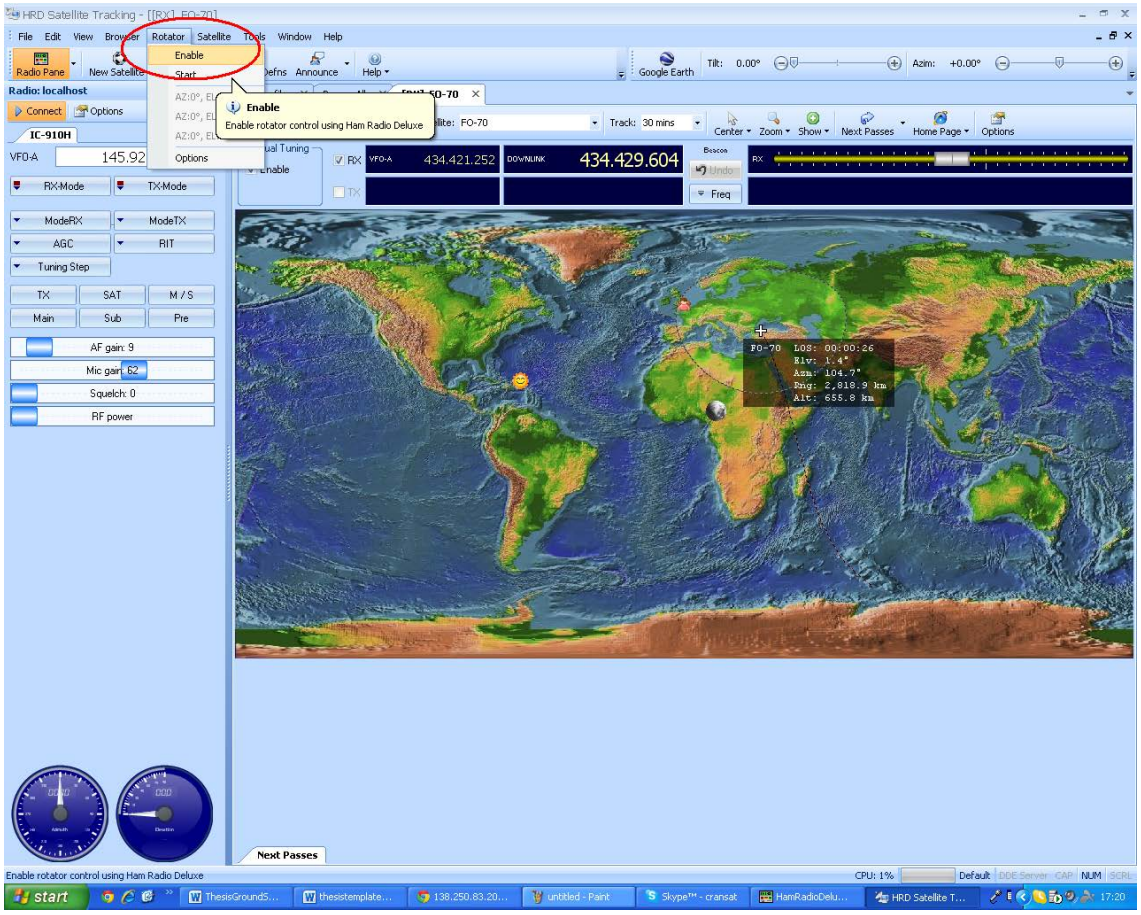




Once **RX** is selected, HRD will automatically adjust the Doppler Effect on Frequency.

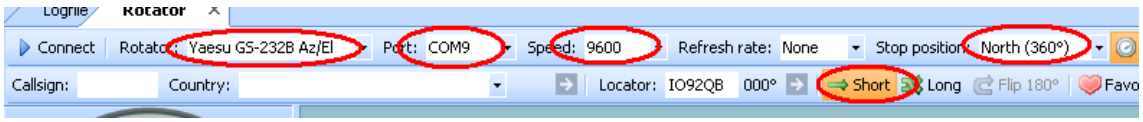
A.3.5 Step5 HRD Rotator

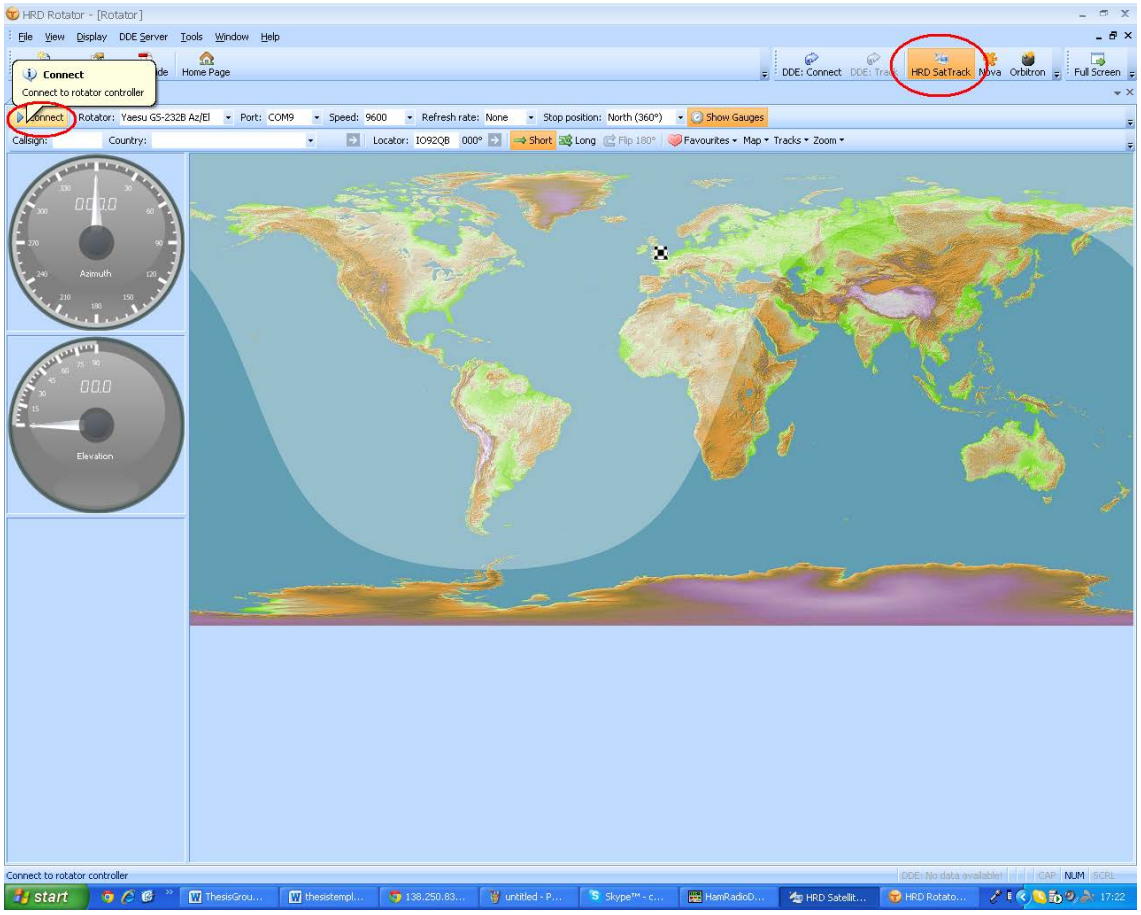
Click **Rotator** and take **Enable** on HRD Satellite Tracking



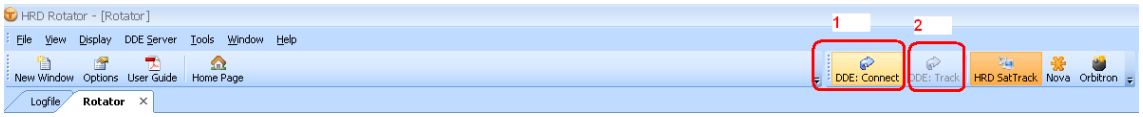
After getting into HRD Rotator, check if **HRD SatTrack** is enabled then click **Connect**

Note: check the configuration of connection of ERC-3D before connecting



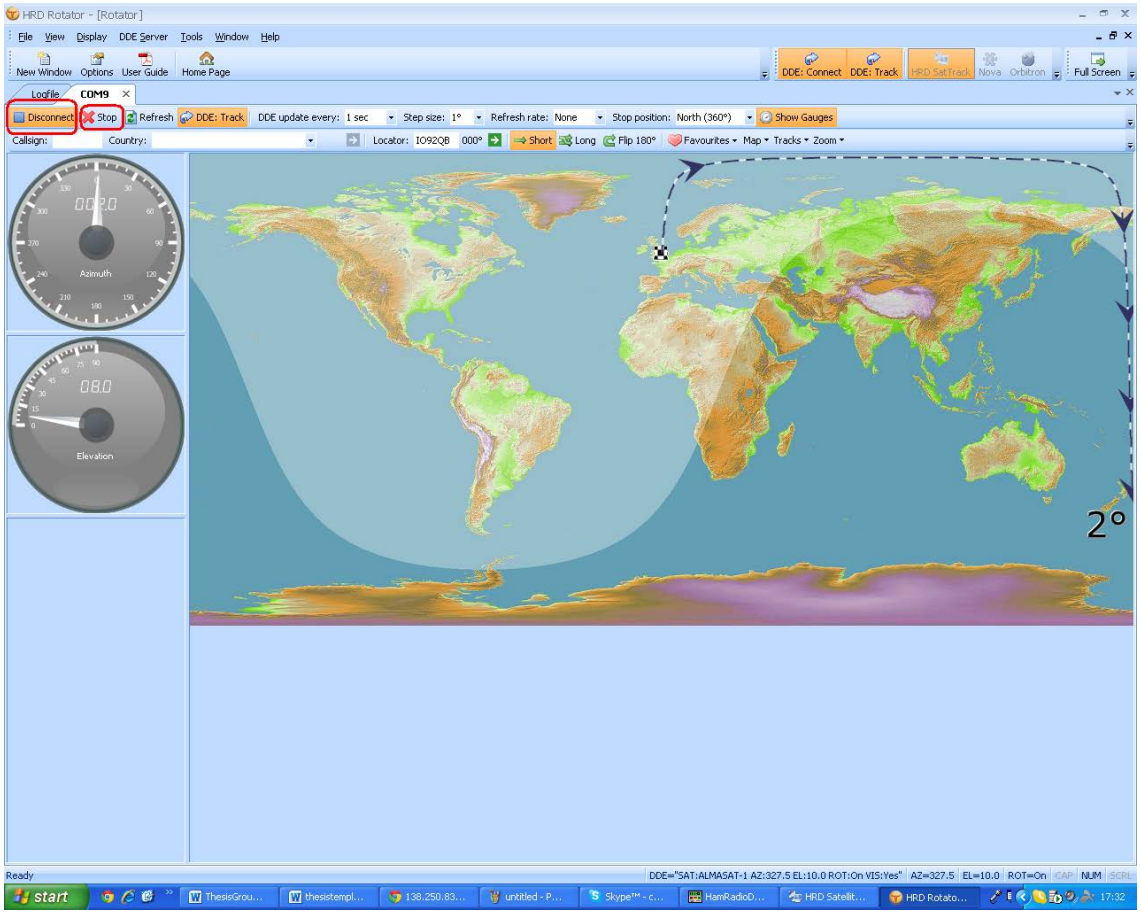


Then click **DDE Connect** and then **DDE Track**



A.3.6 Step6Finishing Operation

When finishing the operation, first click **Stop** to stop motors and then **Disconnect**


HRD Rotator - [Rotator]
File View Display DDE Server Tools Window Help
New Window Options User Guide Home Page
DDE: Connect DDE: Track HRD SatTrack Nova Orbitron Full Screen
Logfile COM9
Disconnect Stop Refresh DDE: Track DDE update every: 1 sec Step size: 1° Refresh rate: None Stop position: North (360°) Show Gauges
Callsign: Country: Locator: IO92QB 000° Short Long Flip 180° Favourites Map Tracks Zoom
Azimuth
Elevation
2°
Ready
DDE="SAT:ALMASAT-1 AZ:327.5 EL:10.0 ROT:On VIS:Yes" AZ=327.5 EL=10.0 ROT=On CAP NUM SCRL
start
17:32

Close HRD Rotator, SatTracker, Radio Control and the power switches.

Close Skype at the end to make sure the radio is **Off**!

A.4 Trouble Shooting

Possible problems maybe encounter during operation

A.4.1 Can not load Webserver

Probably the IP address is expired due to the DHCP in campus. It has to be checked again by Arduino IDE with its Serial Monitor.

Appendix B Webserver Controller Sketch (codes)

```
//ARDUINO 1.0+ ONLY


#include <Ethernet.h>

#include <SPI.h>

#include <Servo.h>

boolean reading = false;



  byte mac[] = { 0xDE, 0xAD, 0xBE, 0xEF, 0xFE, 0x01 };


  EthernetServer server = EthernetServer(80); //port 80

//////////////////////////////////////////////////////////////////////////


String inString = String(35);

Servo radio; // creat subjet to control the radio


String Vhf2;

String Vhf3;

String Vhf4;


String Uhf2;

String Uhf3;
```

```
String Uhf4;
String Sw1;
String Sw2;
String Sw3;
String Sw4;
String Sw5;
String Sw6;
//String Sw3;



int SW1=22;
int SW2=24;
int SW3=26;
int SW4=28;
int SW5=30;
int SW6=32;
//int SW3=15;

int VHF2 = 2;
int VHF3 = 3;
int VHF4 = 4;
```

```
int UHF2 = 5;

int UHF3 = 6;

int UHF4 = 7;



String value2="off";

String value3="off";

String value4="off";

String value6="off";

String value7="off";

String value8="off";

String value9="off";

String value10="off";

String value11="off";

String value12="off";

String value13="off";

String value14="off";

//String value11="off";
```

```
String data;
void setup(){
  Serial.begin(9600);
  radio.attach(9); //attach pin 9 to servo to control radio

  //Pins 10,11,12 & 13 are used by the ethernet shield

    pinMode(SW1, OUTPUT);
    pinMode(SW2, OUTPUT);
    pinMode(SW3, OUTPUT);
    pinMode(SW4, OUTPUT);
    pinMode(SW5, OUTPUT);
    pinMode(SW6, OUTPUT);
    //pinMode(SW3, OUTPUT);
    pinMode(VHF2, OUTPUT);
    pinMode(VHF3, OUTPUT);
    pinMode(VHF4, OUTPUT);
    pinMode(UHF2, OUTPUT);
    pinMode(UHF3, OUTPUT);
    pinMode(UHF4, OUTPUT);
```

```
  Ethernet.begin(mac);
  //Ethernet.begin(mac, ip, gateway, subnet); //for manual setup

  server.begin();
  //Serial.println(Ethernet.localIP());

}

void loop()
{
  EthernetClient client = server.available();
  Serial.println(Ethernet.localIP());
  if(client){
    // an http request ends with a blank line
    boolean current_line_is_blank = true;
    while (client.connected()) {

      if(client.available()) {

        char c = client.read();
        // if we've gotten to the end of the line (received a newline
        // character) and the line is blank, the http request has ended,
```

```
        // so we can send a reply
        if (inString.length() < 35) {
            inString.concat(c);
         }
        if (c == '\n' && current_line_is_blank) {

          // send a standard http response header
          client.println("HTTP/1.1 200 OK");
          client.println("Content-Type: text/html");
          client.println();
          client.println("<html><body><form method=get>");
          //client.println("<SCRIPT language=\"JavaScript\"><!-- var password; var
pass1=\"134655\"; password=prompt('Enter Password',' '); if (password==pass1)
alert('Correct Password! Click OK to Enter!'); else
{ window.location=\"http://www.cranfield.ac.uk//\";}></SCRIPT>");
          client.println("    <font size=\"7\">Cranfield
Ground Station</font><br>");
          client.println("<br><br><font size=\"6\">Polarisation Switch
Controller</font><br><b><i><font color=red><font size=\"5\">NOTE: Only one
switch of each band can be ON, Vertical Polarised if all are
Off</font></font></i></b><br><br><b><font size=\"4\">VHF</font></b><br>");
```

```
//for(int i=1;i < (4 + 1) ;i++){
  //Vhf = String("VHF") + i;

  Vhf2 = String("VHF2") ;
  Vhf3 = String("VHF3") ;
  Vhf4 = String("VHF4") ;




 if(inString.indexOf(Vhf2+"=off")>0 ){
   Serial.println(Vhf2+"on");
   //digitalWrite(VHF[i], HIGH);
   digitalWrite(VHF2, HIGH);
   value2 = "on";
 }else if(inString.indexOf(Vhf2+"=on")>0  ){
   Serial.println(Vhf2+"off");
   //digitalWrite(VHF[i], LOW);
   //value[i] = "on";
   digitalWrite(VHF2, LOW);
   value2 = "off";
```

```
}

if(inString.indexOf(Vhf3+"=off")>0 ){
  Serial.println(Vhf3+"on");
  //digitalWrite(VHF[i], HIGH);
  digitalWrite(VHF3, HIGH);
  value3 = "on";
}else if(inString.indexOf(Vhf3+"=on")>0  ){
  Serial.println(Vhf3+"off");
  //digitalWrite(VHF[i], LOW);
  //value[i] = "on";
  digitalWrite(VHF3, LOW);
  value3 = "off";

}

if(inString.indexOf(Vhf4+"=off")>0 ){
  Serial.println(Vhf4+"on");
  //digitalWrite(VHF[i], HIGH);
  digitalWrite(VHF4, HIGH);
  value4 = "on";
}else if(inString.indexOf(Vhf4+"=on")>0  ){
  Serial.println(Vhf4+"off");
```

```
  //digitalWrite(VHF[i], LOW);
  //value[i] = "on";
  digitalWrite(VHF4, LOW);
  value4 = "off";

}



 Uhf2 = String("UHF2") ;
 Uhf3 = String("UHF3") ;
 Uhf4 = String("UHF4") ;



if(inString.indexOf(Uhf2+"=off")>0 ){
  Serial.println(Uhf2+"on");
  //digitalWrite(VHF[i], HIGH);
  digitalWrite(UHF2, HIGH);
  value6 = "on";
```

```
}else if(inString.indexOf(Uhf2+"=on")>0  ){
  Serial.println(Uhf2+"off");
  //digitalWrite(VHF[i], LOW);
  //value[i] = "on";
  digitalWrite(UHF2, LOW);
  value6 = "off";

}

if(inString.indexOf(Uhf3+"=off")>0 ){
  Serial.println(Uhf3+"on");
  //digitalWrite(VHF[i], HIGH);
  digitalWrite(UHF3, HIGH);
  value7 = "on";
}else if(inString.indexOf(Uhf3+"=on")>0  ){
  Serial.println(Uhf3+"off");
  //digitalWrite(VHF[i], LOW);
  //value[i] = "on";
  digitalWrite(UHF3, LOW);
  value7 = "off";

}
```

```
if(inString.indexOf(Uhf4+"=off")>0 ){
  Serial.println(Uhf4+"on");
  //digitalWrite(VHF[i], HIGH);
  digitalWrite(UHF4, HIGH);
  value8 = "on";
}else if(inString.indexOf(Uhf4+"=on")>0  ){
  Serial.println(Uhf4+"off");
  //digitalWrite(VHF[i], LOW);
  //value[i] = "on";
  digitalWrite(UHF4, LOW);
  value8 = "off";

}

   Sw1 = String("SW1");
   Sw2 = String("SW2");
   Sw3 = String("SW3");
   Sw4 = String("SW4");
   Sw5 = String("SW5");
   Sw6 = String("SW6");
   //Sw3 = String("SW3");

  if(inString.indexOf(Sw1+"=off")>0 ){
```

```
  Serial.println(Sw1+"on");
  //digitalWrite(VHF[i], HIGH);
  digitalWrite(SW1, HIGH);
  value9 = "on";
}else if(inString.indexOf(Sw1+"=on")>0  ){
  Serial.println(Sw1+"off");
  //digitalWrite(VHF[i], LOW);
  //value[i] = "on";
  digitalWrite(SW1, LOW);
  value9 = "off";

}

if(inString.indexOf(Sw2+"=off")>0 ){
  Serial.println(Sw2+"on");
  //digitalWrite(VHF[i], HIGH);
  digitalWrite(SW2, HIGH);
  value10 = "on";
}else if(inString.indexOf(Sw2+"=on")>0  ){
  Serial.println(Sw2+"off");
  //digitalWrite(VHF[i], LOW);
  //value[i] = "on";
  digitalWrite(SW2, LOW);
```

```
  value10 = "off";

}

if(inString.indexOf(Sw3+"=off")>0 ){
  Serial.println(Sw3+"on");
  //digitalWrite(VHF[i], HIGH);
  digitalWrite(SW3, HIGH);
  value11 = "on";
}else if(inString.indexOf(Sw3+"=on")>0  ){
  Serial.println(Sw3+"off");
  //digitalWrite(VHF[i], LOW);
  //value[i] = "on";
  digitalWrite(SW3, LOW);
  value11 = "off";

}

if(inString.indexOf(Sw4+"=off")>0 ){
  Serial.println(Sw4+"on");
  //digitalWrite(VHF[i], HIGH);
  digitalWrite(SW4, HIGH);
  value12 = "on";
```

```
}else if(inString.indexOf(Sw4+"=on")>0  ){
  Serial.println(Sw4+"off");
  //digitalWrite(VHF[i], LOW);
  //value[i] = "on";
  digitalWrite(SW4, LOW);
  value12 = "off";

}
if(inString.indexOf(Sw5+"=off")>0 ){
  Serial.println(Sw5+"on");
  //digitalWrite(VHF[i], HIGH);
  digitalWrite(SW5, HIGH);
  value13 = "on";
}else if(inString.indexOf(Sw5+"=on")>0  ){
  Serial.println(Sw5+"off");
  //digitalWrite(VHF[i], LOW);
  //value[i] = "on";
  digitalWrite(SW5, LOW);
  value13 = "off";

}

if(inString.indexOf(Sw6+"=off")>0 ){
```

```
      Serial.println(Sw6+"on");
      //digitalWrite(VHF[i], HIGH);
      digitalWrite(SW6, HIGH);
      value14 = "on";
    }else if(inString.indexOf(Sw6+"=on")>0  ){
      Serial.println(Sw6+"off");
      //digitalWrite(VHF[i], LOW);
      //value[i] = "on";
      digitalWrite(SW6, LOW);
      value14 = "off";

    }
```

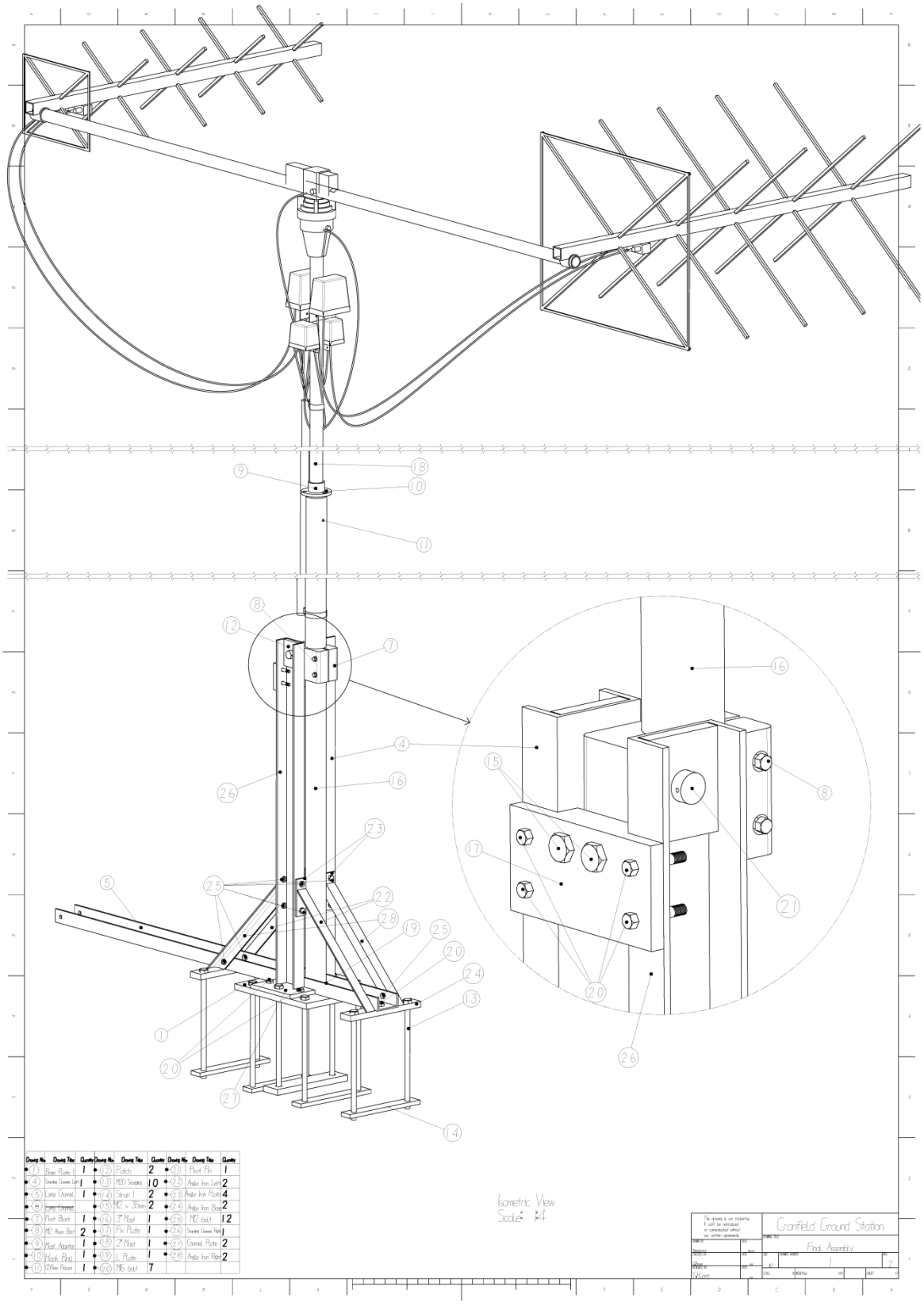
```
    // client.println("<br><input type=submit name="+Vhf1+"
value="+value1+">Vertical ");
     client.println(" <input type=submit name="+Vhf2+"
value="+value2+">Horizontal");
     client.println(" <input type=submit name="+Vhf3+"
value="+value3+">RHCP ");
```

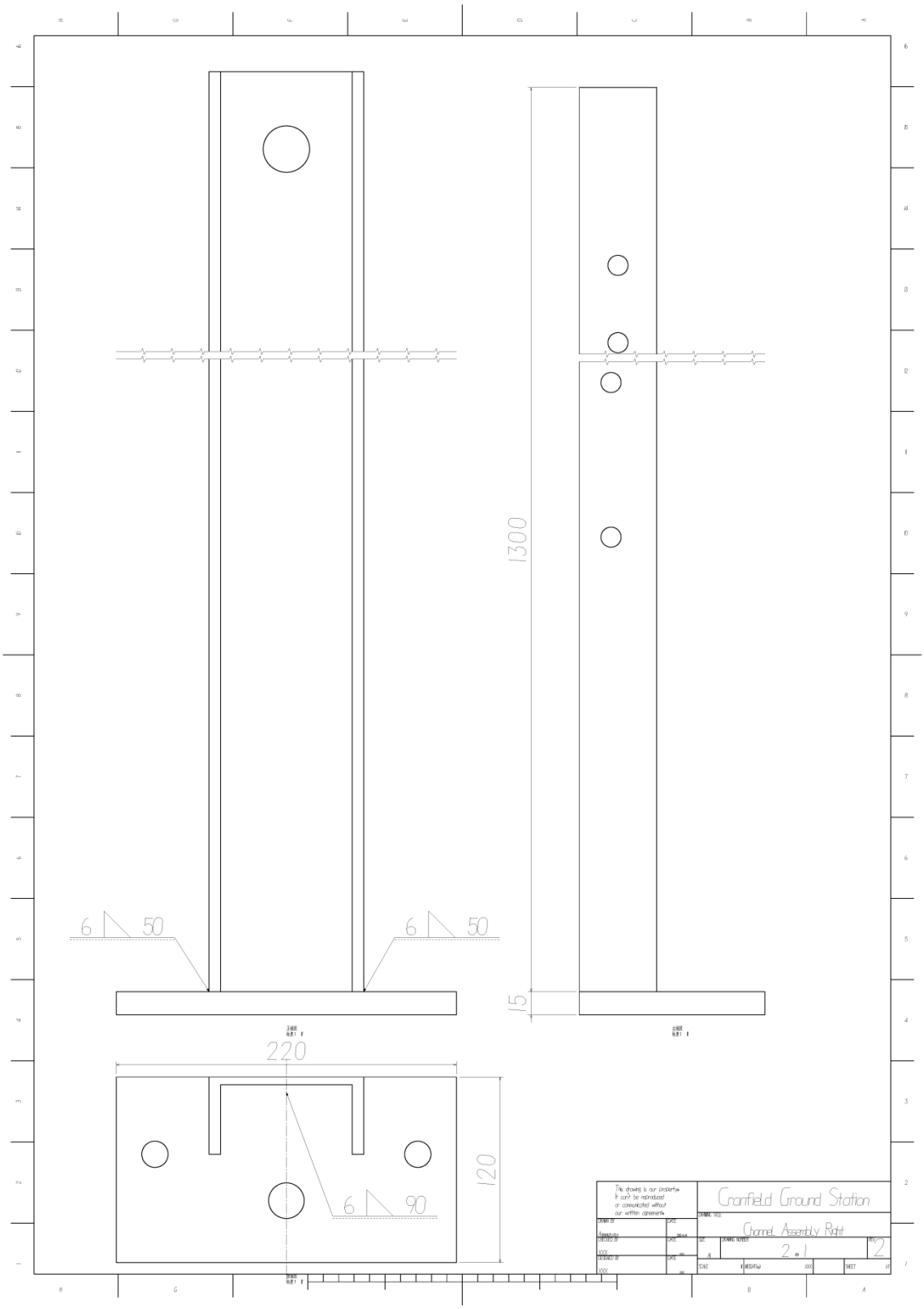
```
        client.println(" <input type=submit name="+Vhf4+"
value="+value4+">LHCP");


        client.println("<br><br><b><font size=\"4\">UHF</font></b><br>");



        //client.println("<br><input type=submit name="+Uhf1+"
value="+value5+">Vertical ");

        client.println(" <input type=submit name="+Uhf2+"
value="+value6+">Horizontal ");

        client.println(" <input type=submit name="+Uhf3+"
value="+value7+">RHCP ");

        client.println(" <input type=submit name="+Uhf4+"
value="+value8+">LHCP");



        client.println("<br><br><font size=\"6\">Power Switches
Controller</font>");
```

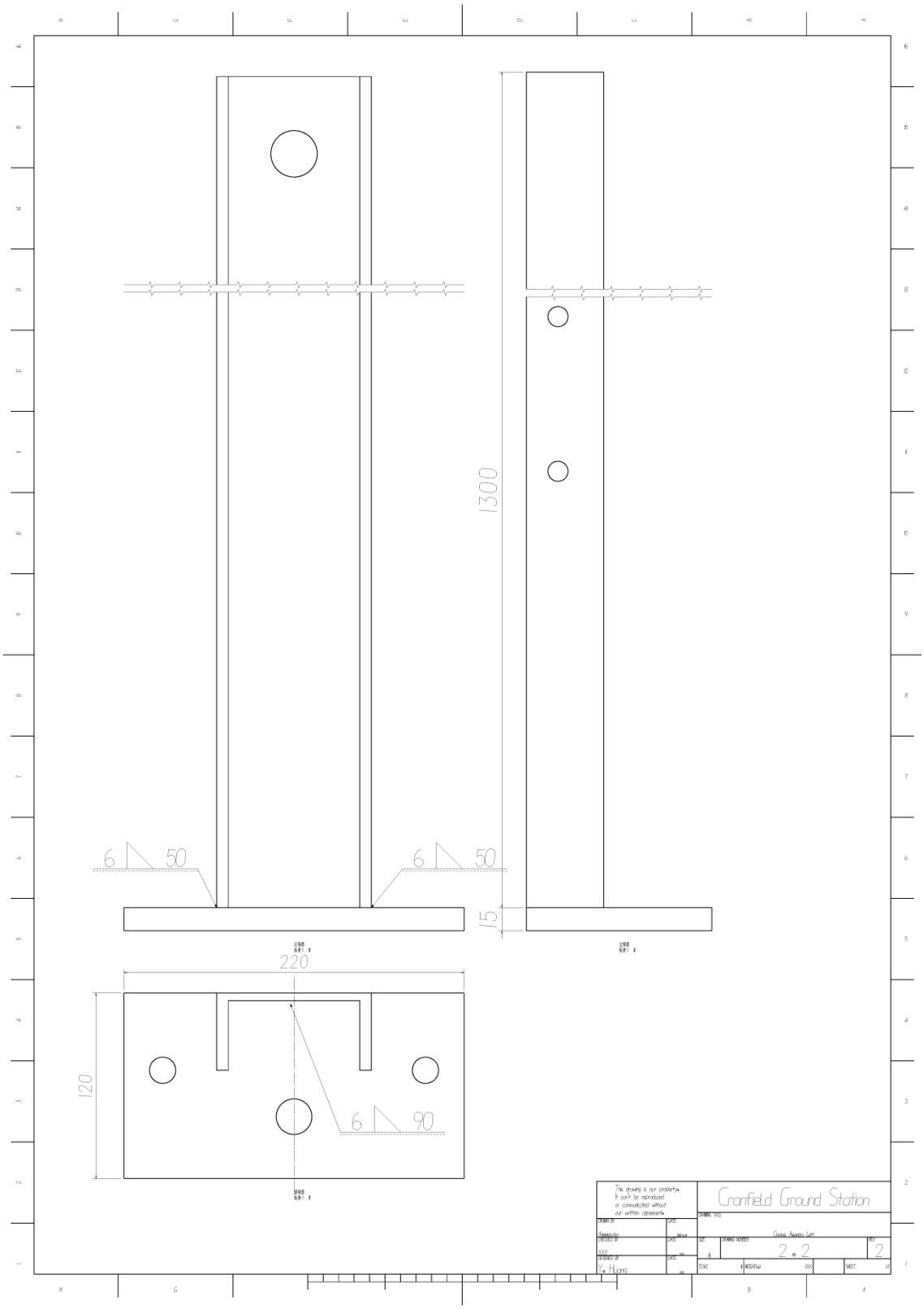
```
        client.println("<br><br><br><input type=submit name="+Sw1+"
value="+value9+">TNC ");

        client.println(" <input type=submit name="+Sw2+"
value="+value10+">Rotator ");

        client.println(" <input type=submit name="+Sw3+"
value="+value11+">Computer ");

        client.println(" <input type=submit name="+Sw4+"
value="+value12+">Radio ");

        client.println(" <input type=submit name="+Sw5+"
value="+value13+">S5 ");

        client.println(" <input type=submit name="+Sw6+"
value="+value14+">ERC-3D ");

       // client.println(" <input type=submit name="+Sw3+"
value="+value11+">S3 ");


         client.println("<br><br><br><b><font size=\"4\">Radio
On/Off</font></b><br><button name=\"radio\" value=\"5\">Click</button>");


       if (inString.indexOf("radio")>0 ){

         radio.write(140);

         delay(800);

         Serial.println("radio on");

       }else{

         radio.write(80);

       }
```

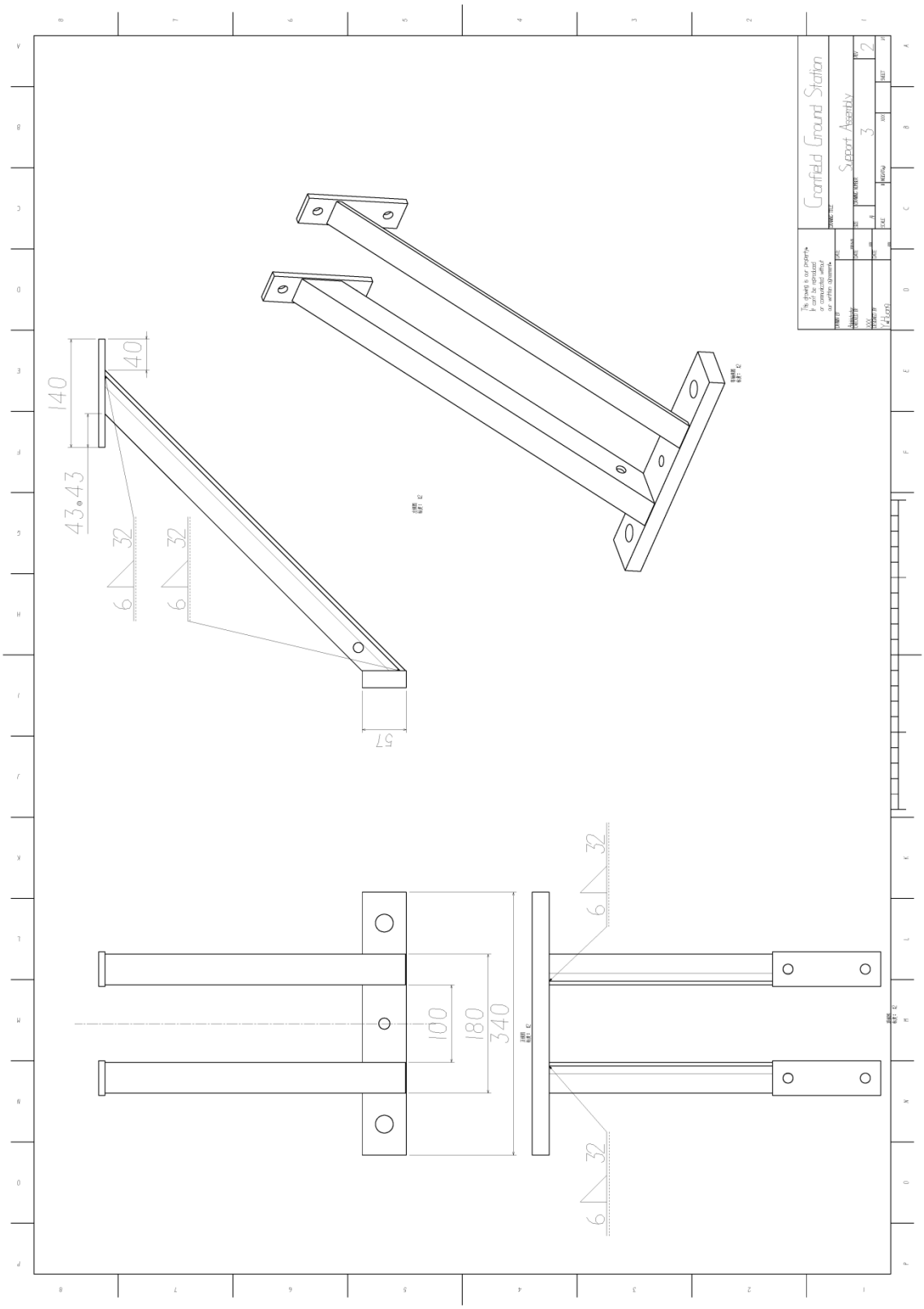
```
          client.println("</from></html></body>");
          break;
        }
        if (c == '\n') {
          // we're starting a new line
          current_line_is_blank = true;
        } else if (c != '\r') {
          // we've gotten a character on the current line
          current_line_is_blank = false;
        }
      }
    }
    // give the web browser time to receive the data
    delay(1);
    inString = "";
    client.stop();
  }
}
```

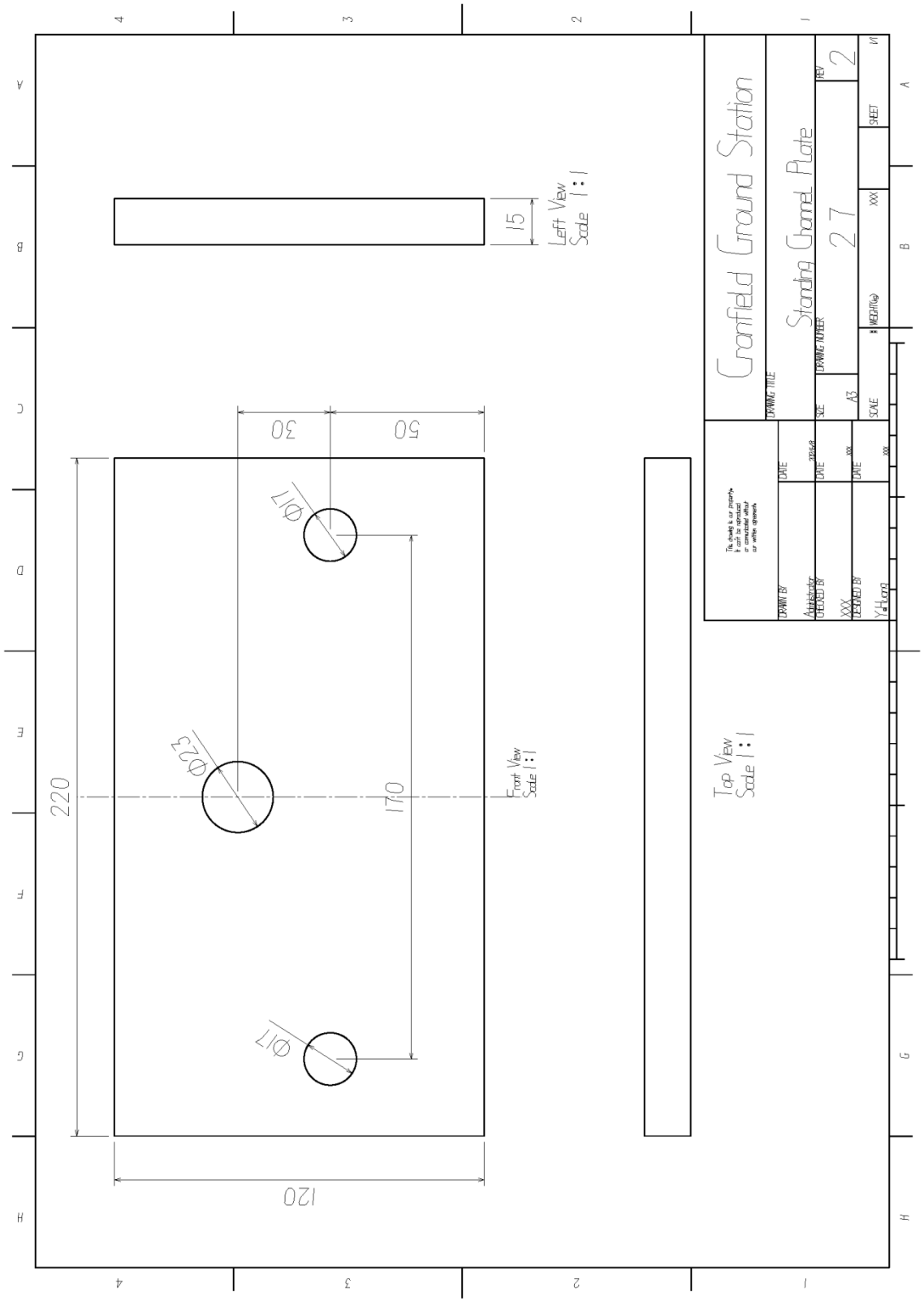
Appendix C Mast Support Structure Drawings

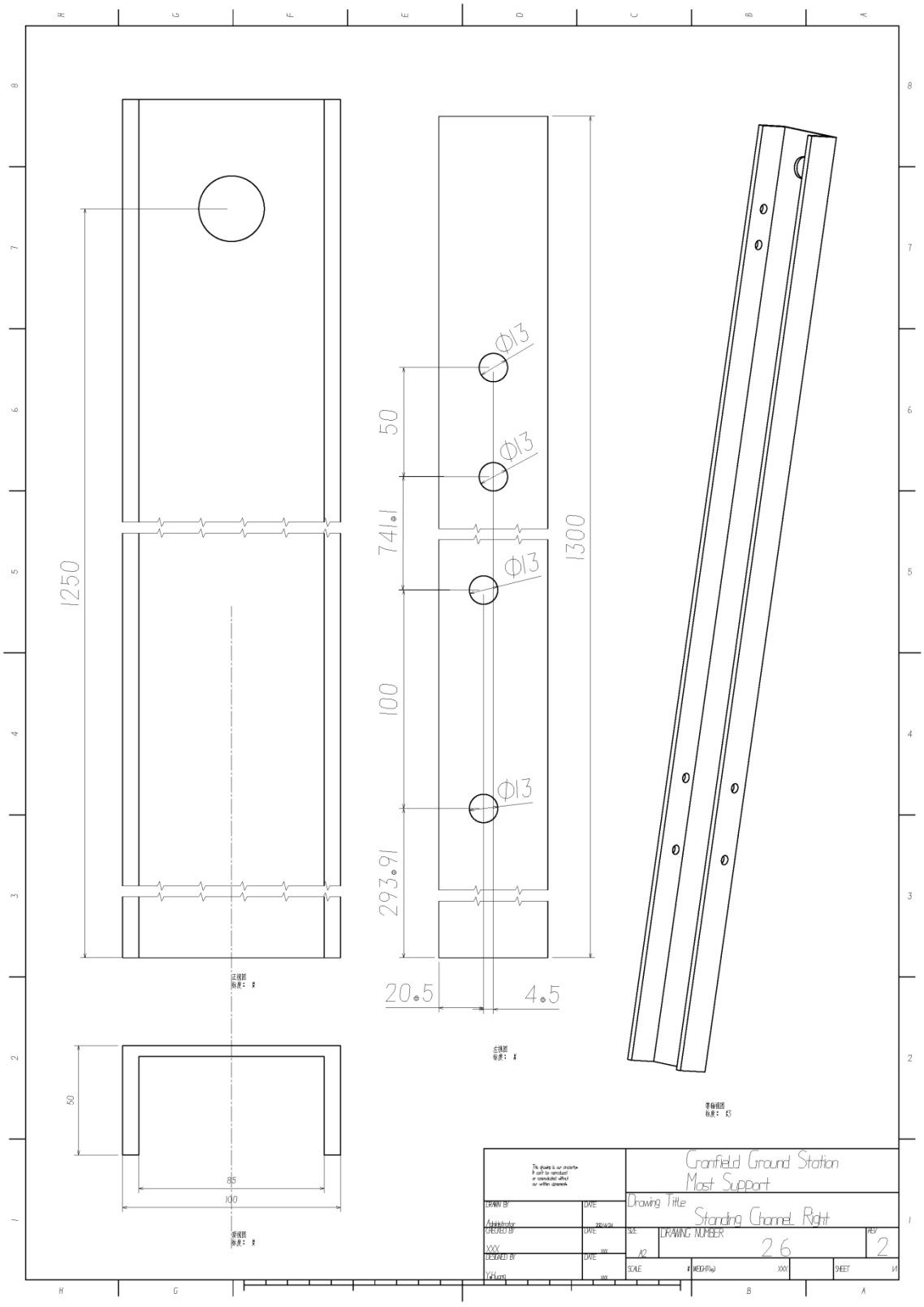


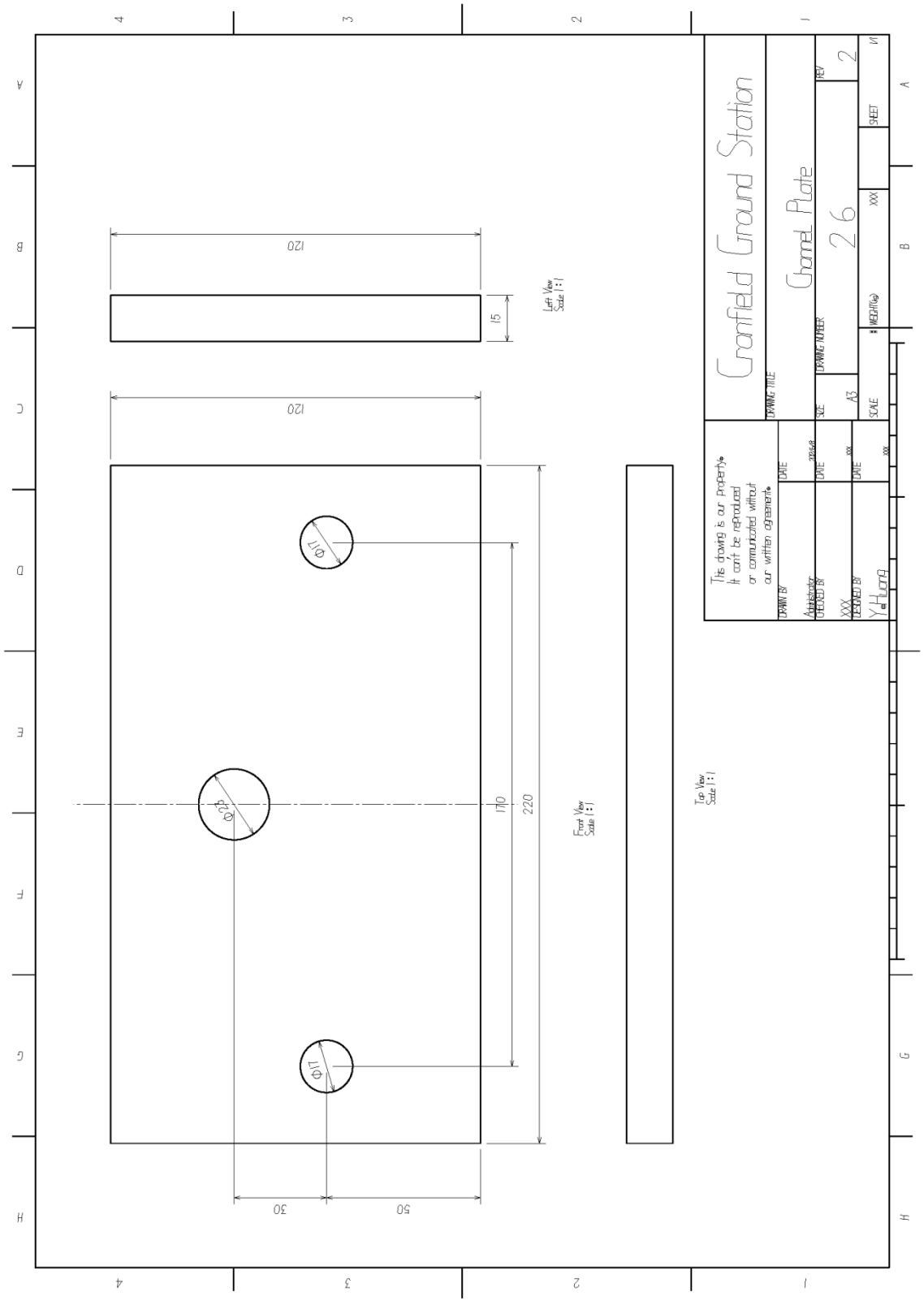

1300
15
220
120
6
50
6
50
6
90
Cranfield Ground Station
Channel Assembly Right
2:1
A1

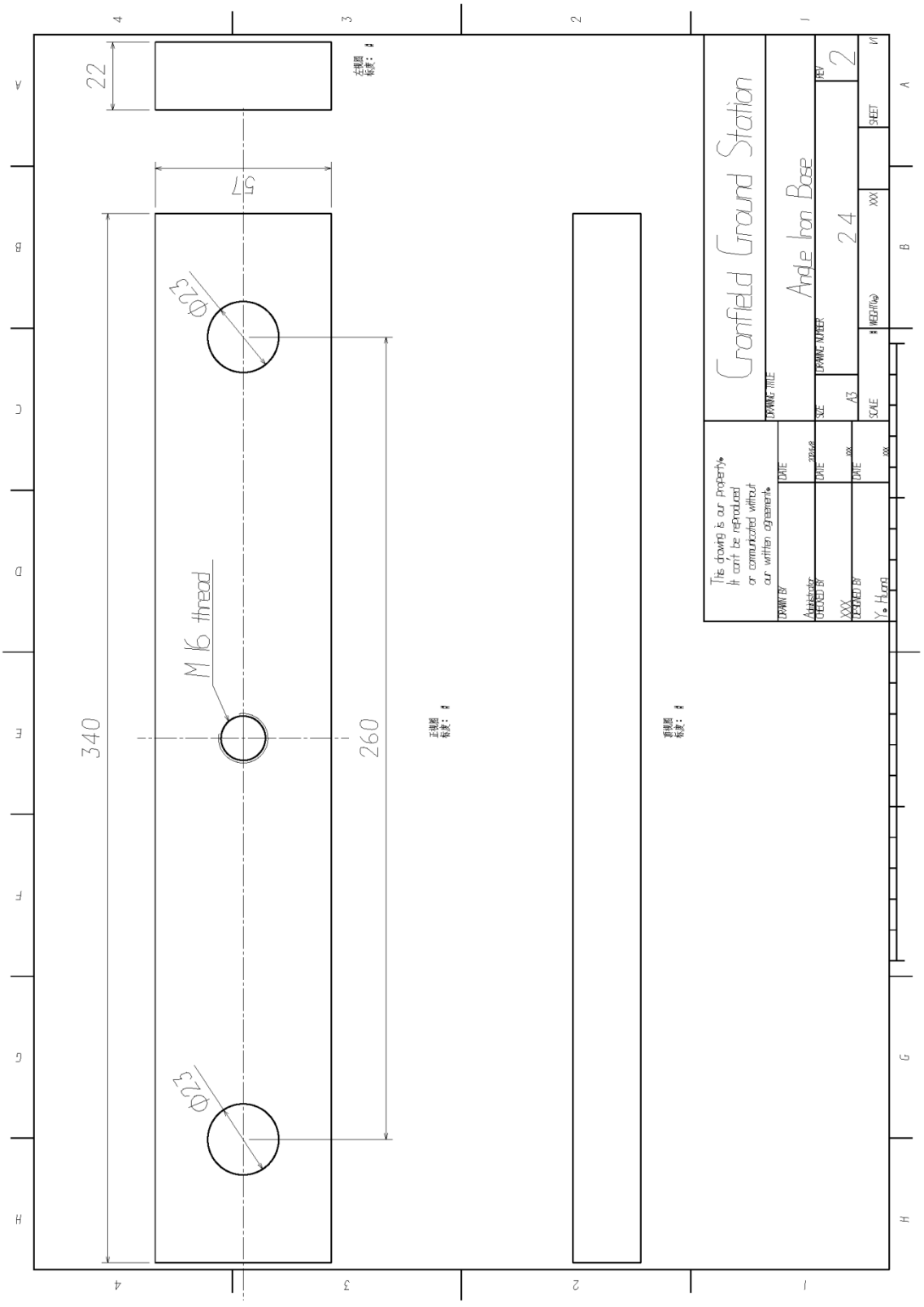

1300
6 50
6 50
15
220
120
6 90
Cranfield Ground Station
2.2
2


Cranfield Ground Station
Support Assembly
3
2
140
40
43.43
32
32
6
6
37
100
180
340
32
32
6
6


Cranfield Ground Station
Standing Ground Plate
27
2
A3
1:1
Left View
Scale 1:1
15
Front View
Scale 1:1
30
50
220
170
120
Ø17
Ø17
Ø23
Top View
Scale 1:1


1250
50
741.41
100
293.91
1300
Φ13
Φ13
Φ13
Φ13
20.5
4.5
50
85
100
Cranfield Ground Station
Mast Support
Drawing Title
Standing Channel Right
DRAWING NUMBER
26
REV
2
A2
SHEET


Cranfield Ground Station
Gimbal Plate
2.6
DRAWING TITLE
DRAWING NUMBER
REV
SHEET
SCALE
A3
DRAWN BY
CHECKED BY
DESIGNED BY
DATE
This drawing is our property.
It can't be reproduced
or communicated without
our written agreement.
120
15
120
Left View
Scale 1 : 1
Ø17
Ø22
170
220
Front View
Scale 1 : 1
Top View
Scale 1 : 1
30
50


22
57
Ø23
M16 thread
340
260
Ø23
Cranfield Ground Station
Angle Iron Base
2.4
DRAWING TITLE
DRAWING NUMBER
REV
SHEET
SCALE
A3
DRAWN BY
CHECKED BY
DESIGNED BY
Ye Hong
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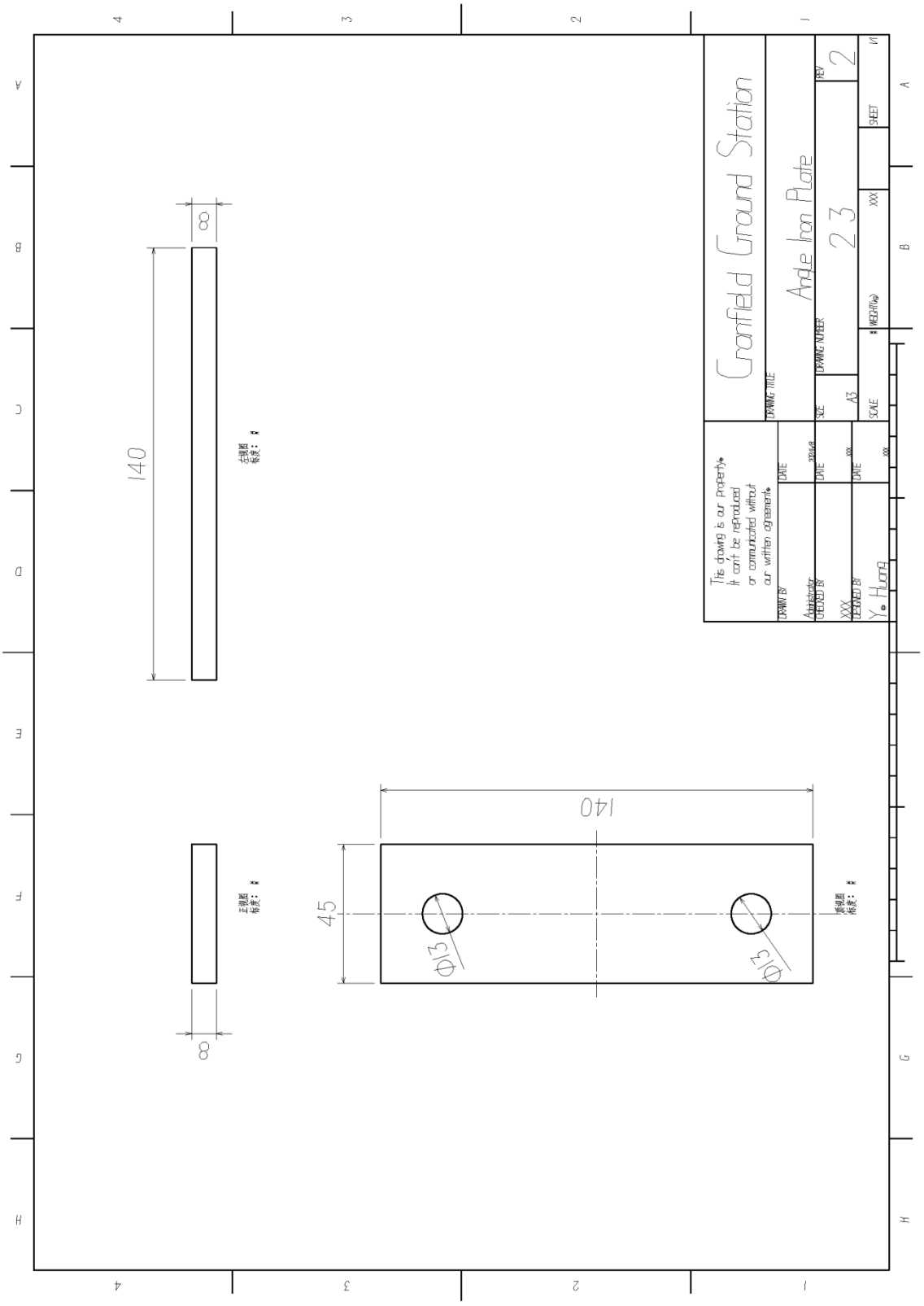
Cranfield Ground Station
Angle Iron Plate
2 3
2
XXX
A3
XXX
XXX
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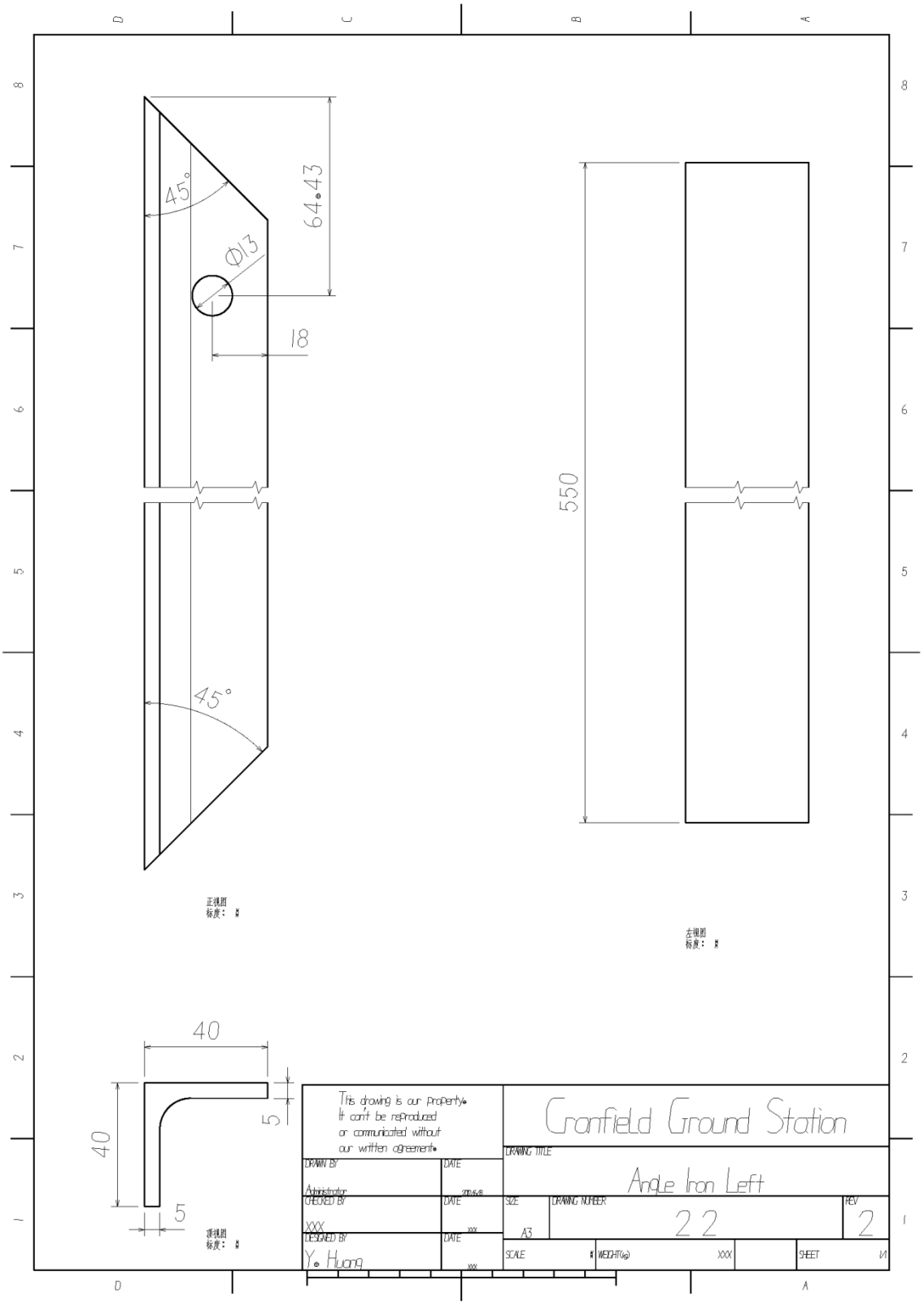
DRAWN BY
Ashley Gray
CHECKED BY
XXX
DESIGNED BY
Y. Huang
DATE
DATE
DATE
140
8
8
45
140
φ13
φ13


45°
64.43
Ø13
18
550
45°
正视图
标度： 1
左视图
标度： 1
40
40
5
5
俯视图
标度： 1
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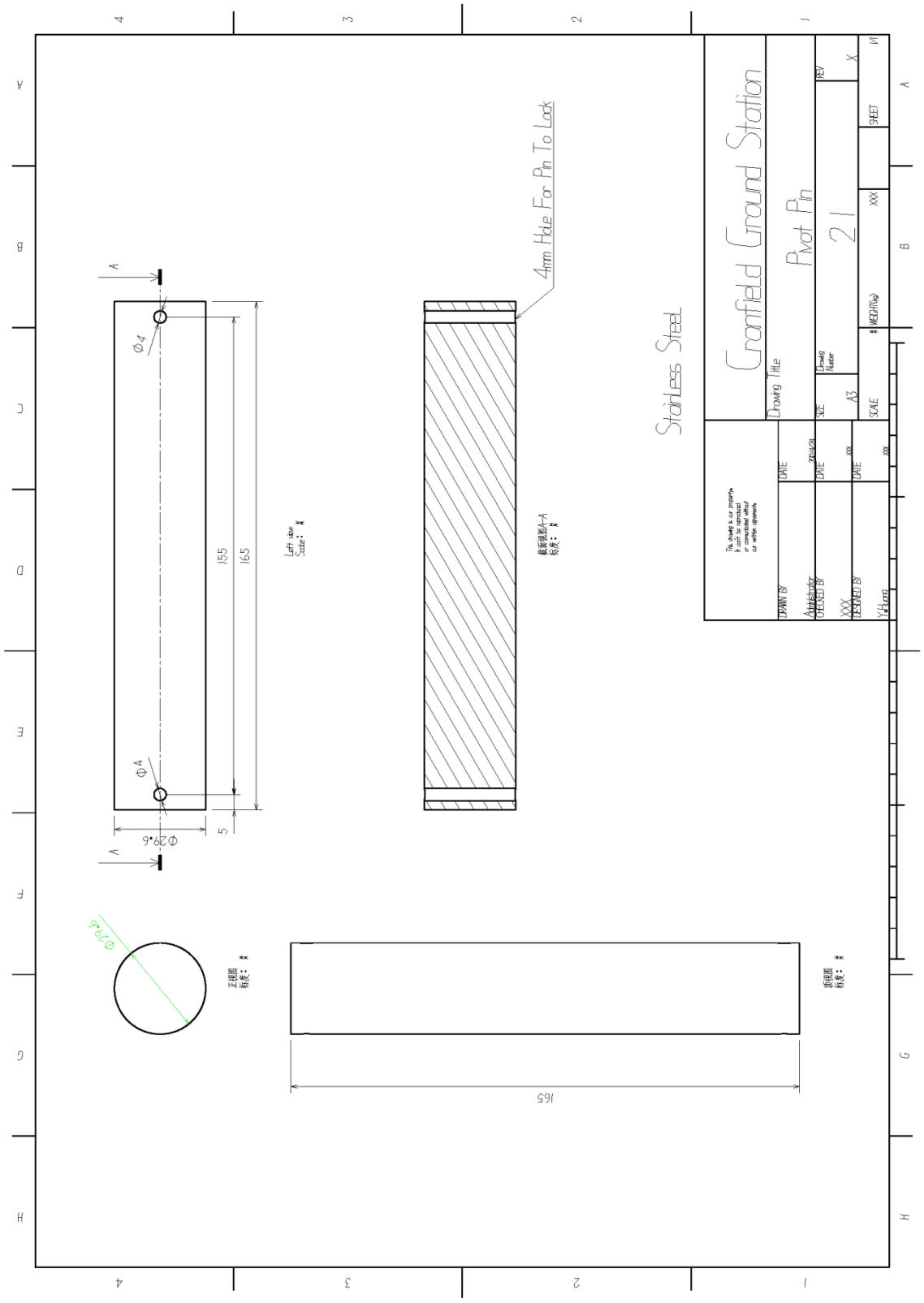
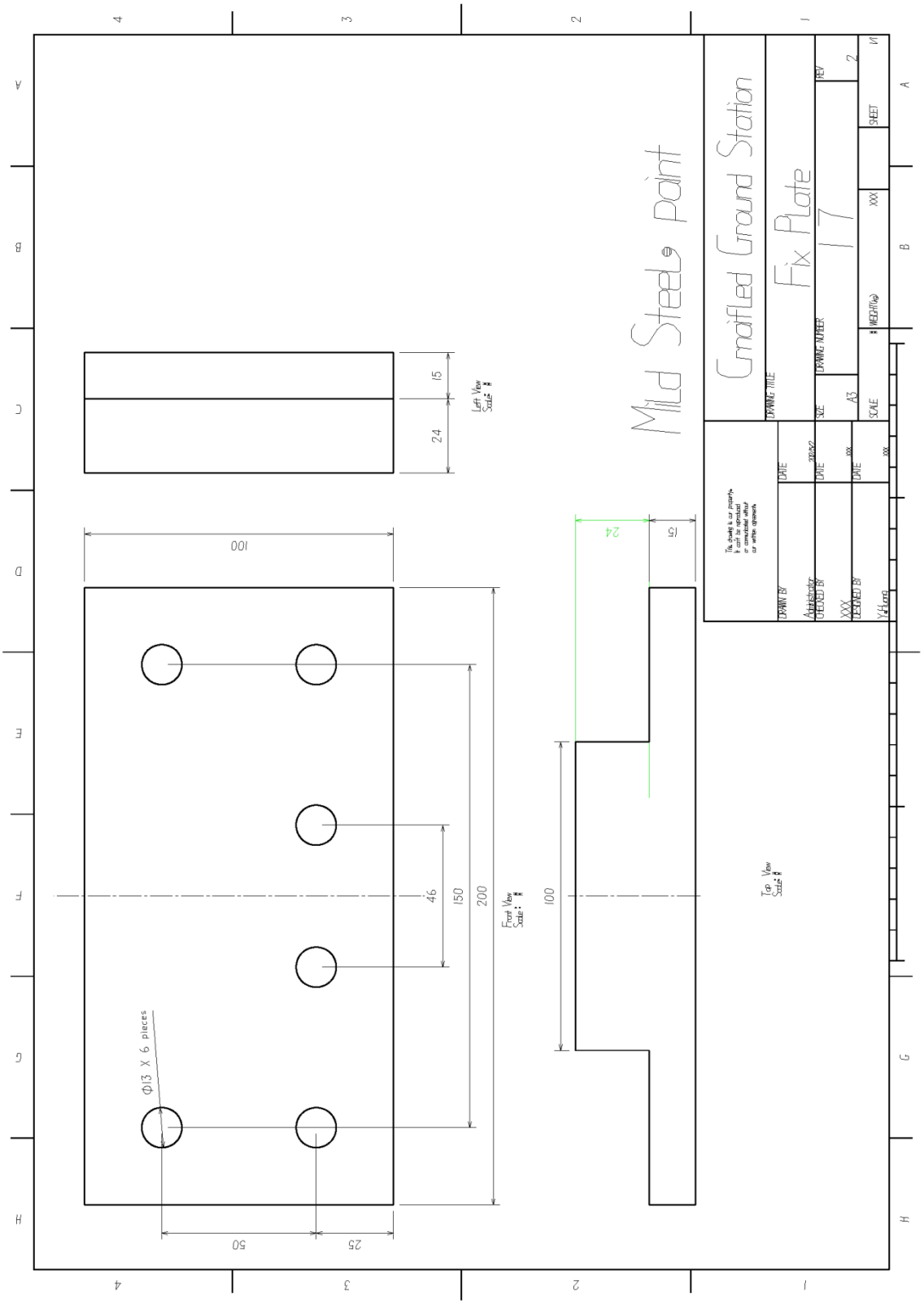
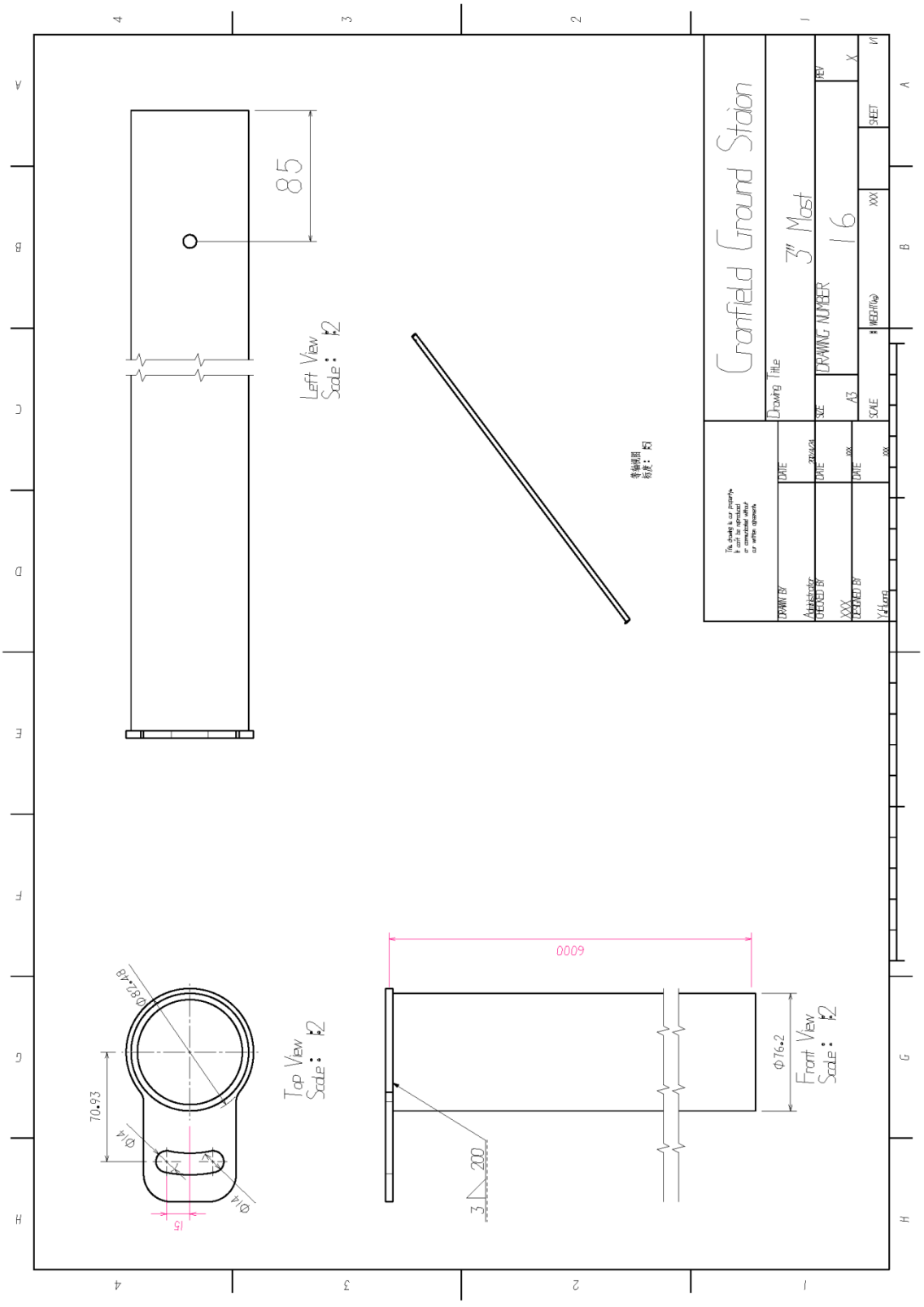
Granfield Ground Station
DRAWN BY
Administrator
DATE
CHECKED BY
XXX
DATE
DESIGNED BY
Y. Huang
DATE
DRAWING TITLE
Angle Iron Left
SIZE
A3
DRAWING NUMBER
2 2
REV
2
SCALE
1
WEIGHT(kg)
XXX
SHEET
1/1

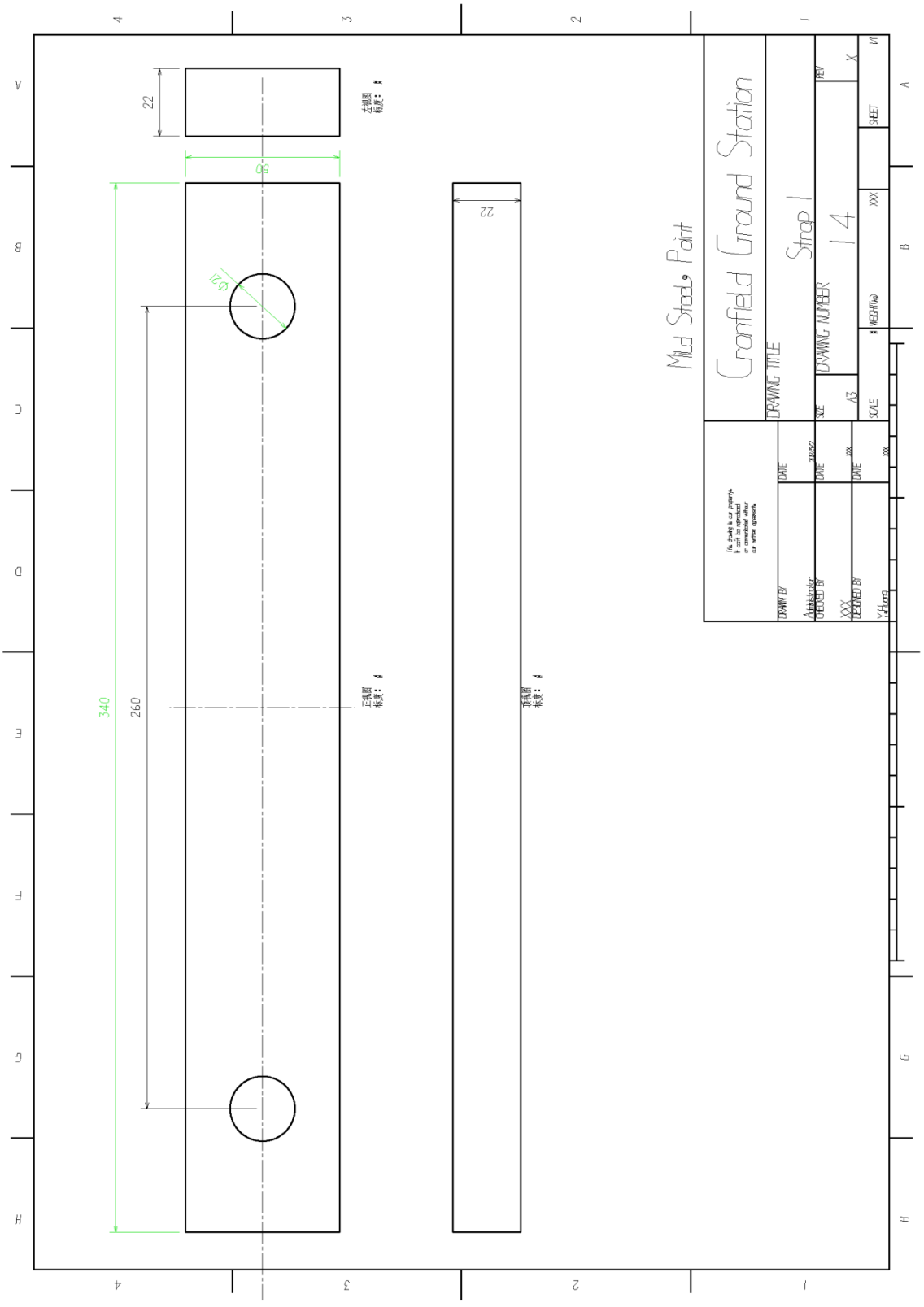

Cranfield Ground Station
Pivot Pin
2.1
Stainless Steel
4mm Hole For Pin To Lock
Left View
Scale: X
截面圖A-A
比例: X
正視圖
比例: X
俯視圖
比例: X
Ø4
Ø28.6
155
165
5
165
DRAWN BY
CHECKED BY
DESIGNED BY
DATE
SCALE
SHEET
REV

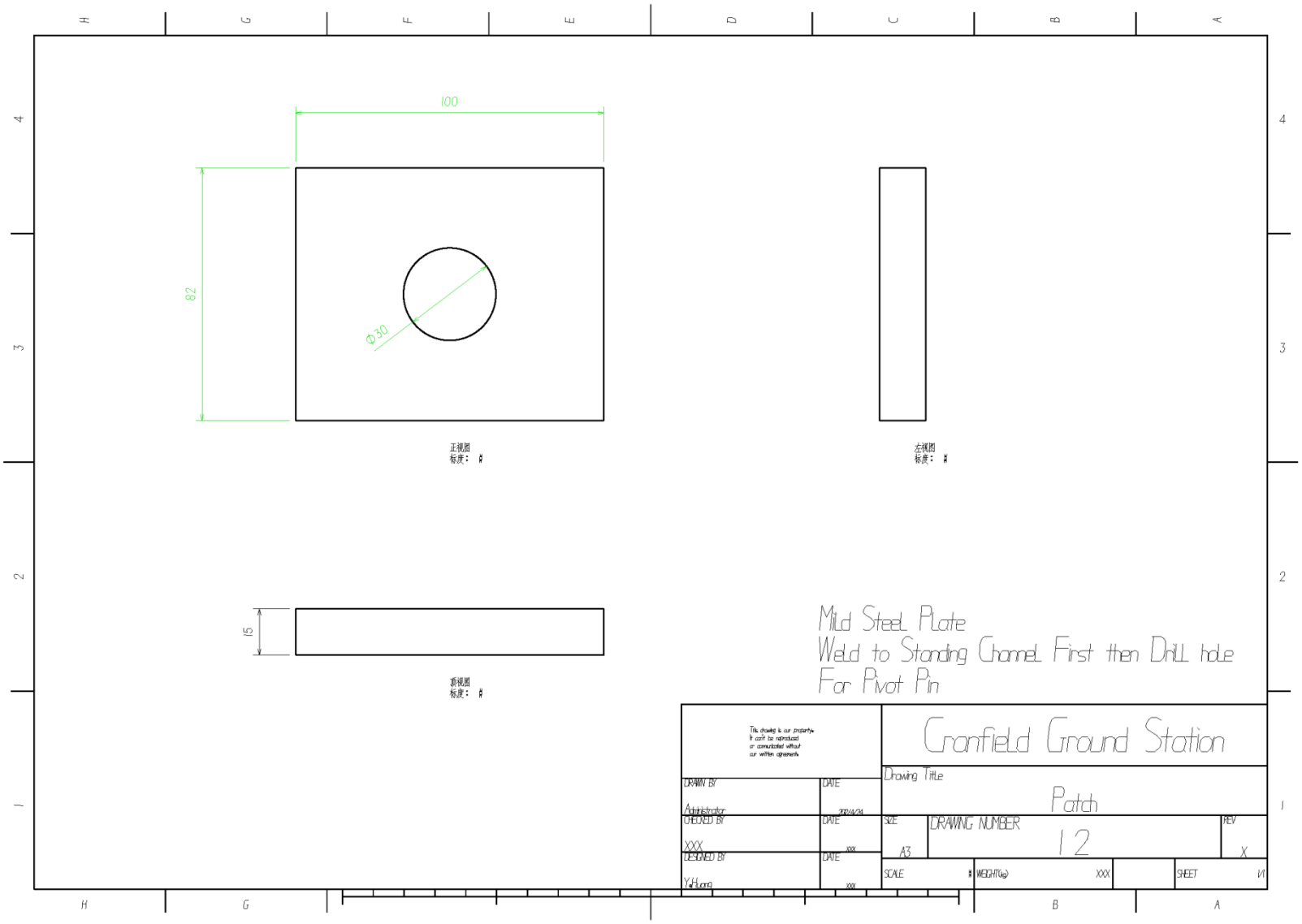
Mild Steel Paint
Cranfield Ground Station
DRAWING TITLE
LPlate
DRAWING NUMBER
19
REV
2
SHEET
1
SCALE
A3
WEIGHT(kg)
XXX
DRAWN BY
CHECKED BY
XXX
DESIGNED BY
DATE
24
R18
Φ14
47
97
70.93
15
R72.5
R10
Φ82.48

Cranfield Ground Station
2" Mast
18
2" Galvanised Tube
150
50
Ø8.5
Ø6
Ø48.3
Ø40
3000
Left View
Scale: 1:1
Top View
Scale: 1:1
Front View
Scale: 1:1
DRAWN BY
CHECKED BY
DESIGNED BY
DRAWING NUMBER
SCALE
SHEET
REV


Mild Steel & Paint
Graifled Ground Station
Fix Plate 17
DRAWING TITLE
DRAWING NUMBER
REV
SHEET
SCALE
A3
DRAWN BY
CHECKED BY
DESIGNED BY
DATE
Left View
Scale 1:1
Front View
Scale 1:1
Top View
Scale 1:1
100
15
24
46
150
200
Φ13 X 6 pieces
50
25
75


Cranfield Ground Stain
3" Mast
16
85
Left View
Scale: 1:2
Top View
Scale: 1:2
Front View
Scale: 1:2
6000
Φ76±2
Φ82±1.8
70.93
Φ14
15
3
200


Mild Steel, Paint
Cranfield Ground Station
DRAWING TITLE
Strap 1
DRAWING NUMBER
14
REV
X
SHEET
1/1
SCALE
A3
SCALE
1:1
WEIGHT(kg)
XXX
DRAWN BY
CHECKED BY
XXX
DESIGNED BY
DATE
22
25
Ø21
340
260
22


100
82
Ø30
正视图
标度： #
左视图
标度： #
15
俯视图
标度： #
Mild Steel Plate
Weld to Standing Channel First then Drill hole
For Pivot Pin
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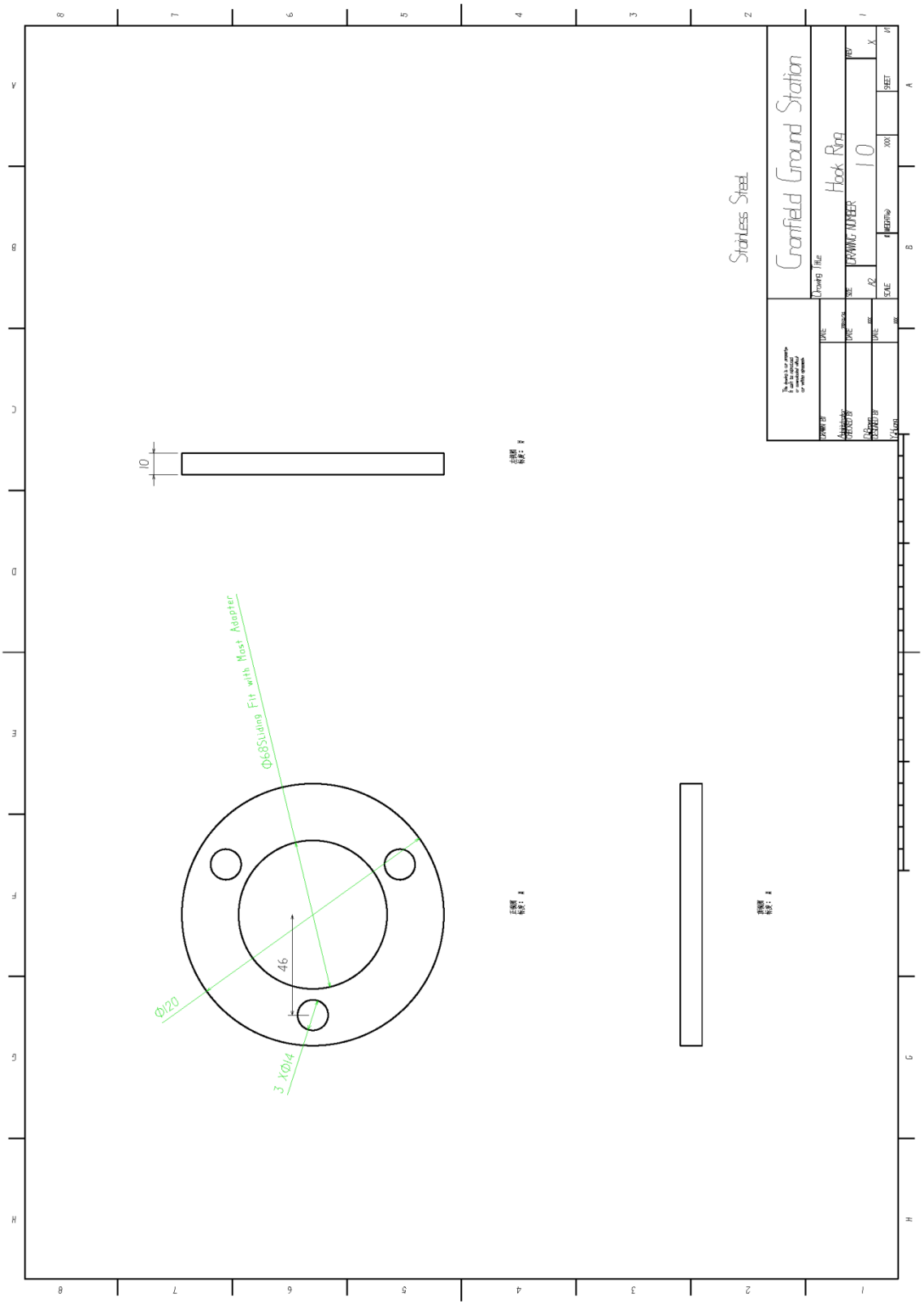
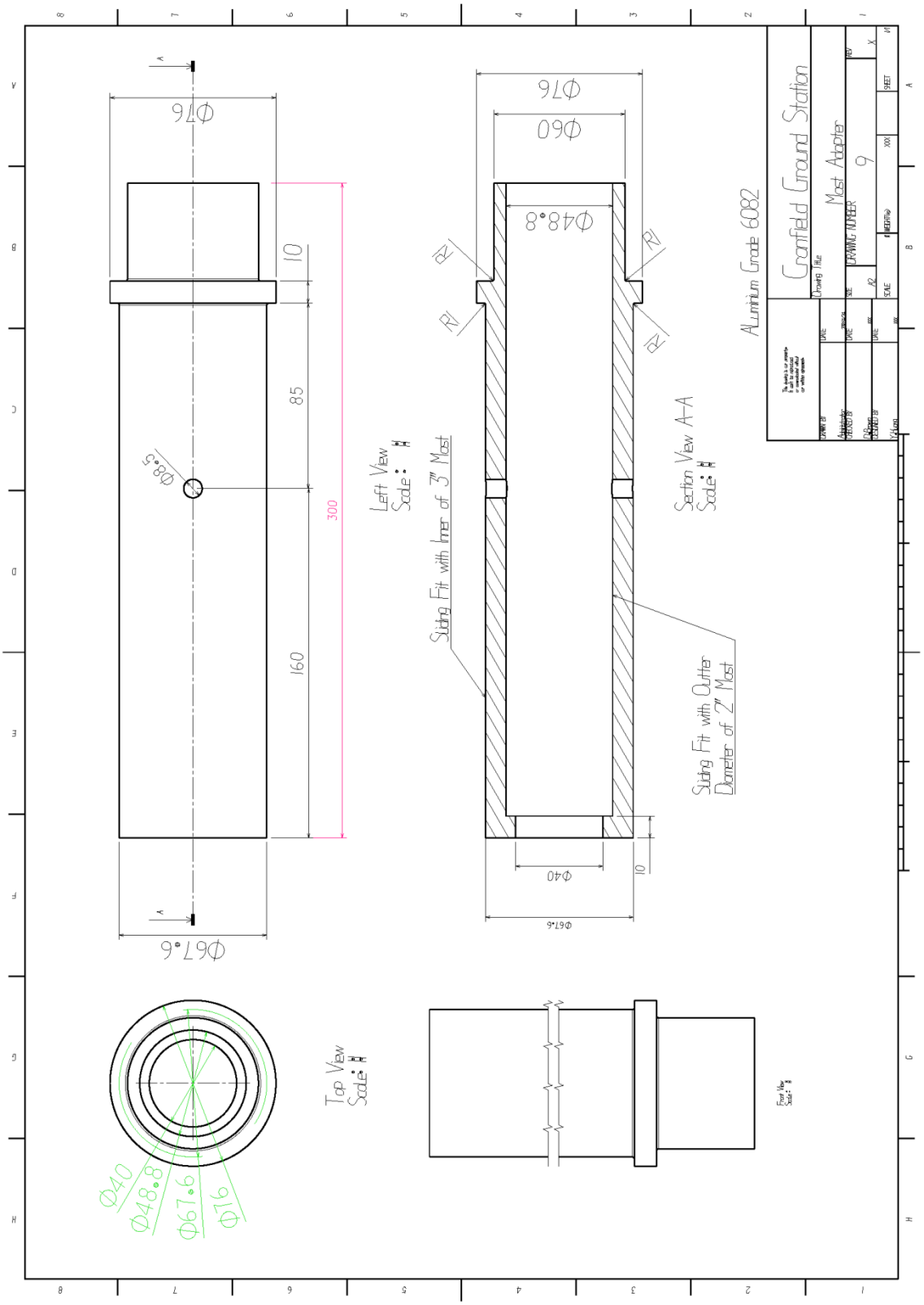
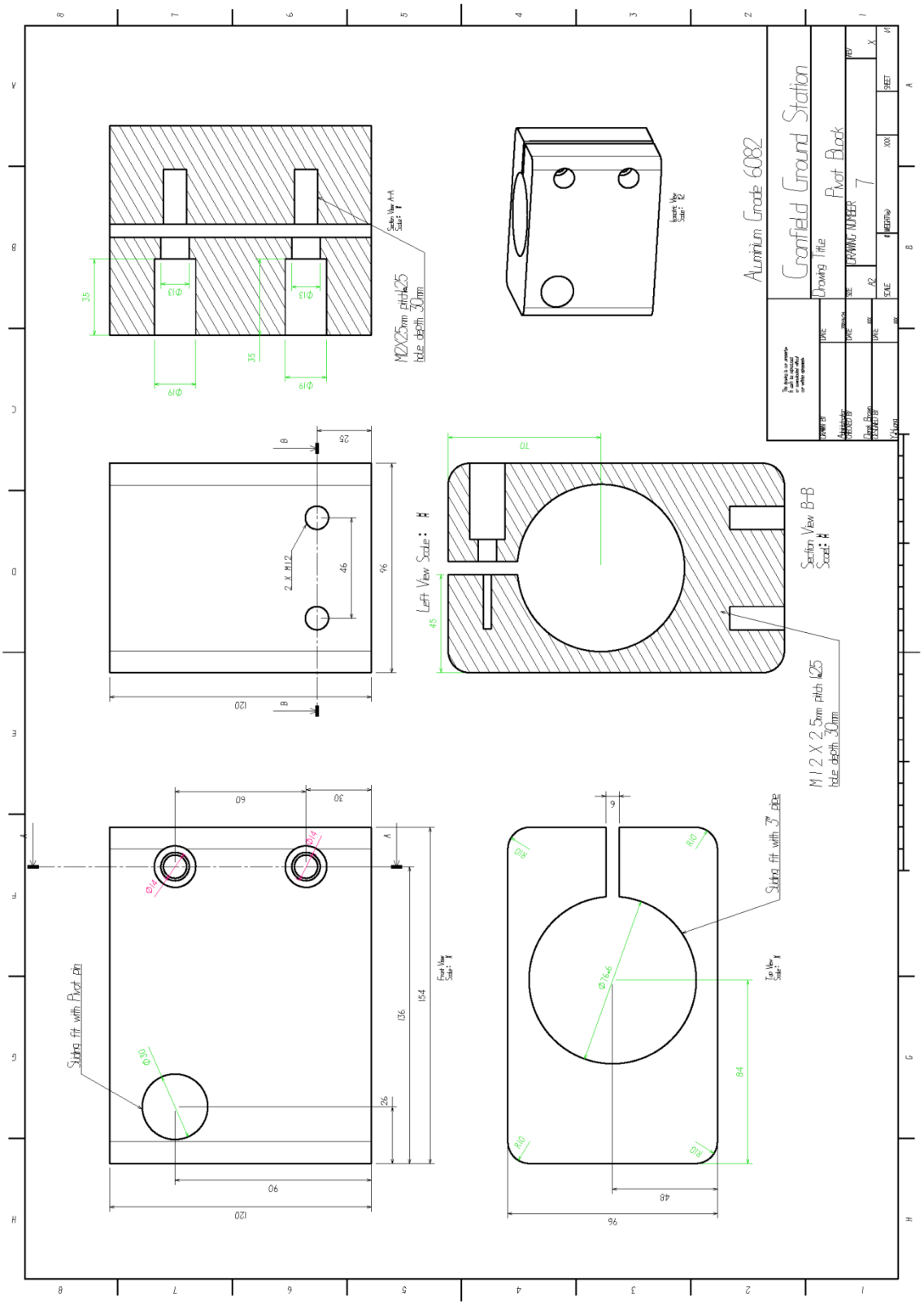
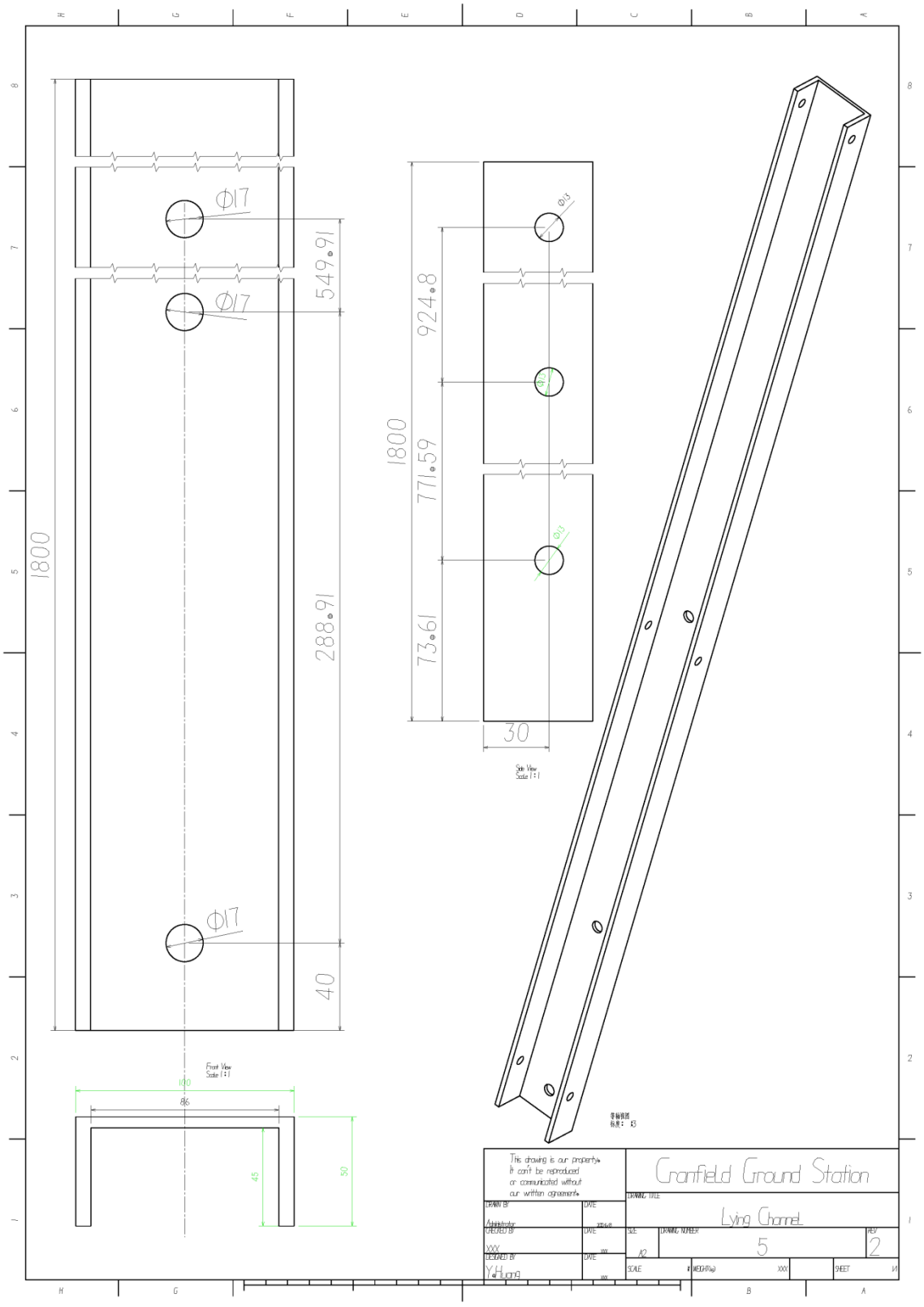
DRAWN BY
Administrator
DATE
2024/4/24
CHECKED BY
XXX
DATE
XXX
DESIGNED BY
Y.H.Liang
DATE
XXX
Cranfield Ground Station
Drawing Title
Patch
SIZE
A3
DRAWING NUMBER
12
REV
X
SCALE
#
WEIGHT(g)
XXX
SHEET
1/1


Stainless Steel
Cranfield Ground Station
Hook Ring
10
10
Φ68Sliding Fit with Mast Adapter
46
Φ120
3 XΦ14


Cranfield Ground Station
Mast Adapter
Aluminium Grade 6082
Left View
Scale : H
Section View A-A
Scale : H
Top View
Scale : H
Front View
Scale : H
Sliding Fit with Inner of 3" Mast
Sliding Fit with Outter Diameter of 2" Mast
Ø76
Ø60
Ø48.8
Ø67.6
Ø40
Ø16
Ø8.5
10
85
160
300
R2


Aluminium Grade 6082
Cranfield Ground Station
Drawing Title
Pivot Block
DRAWING NUMBER 7
SIZE A2
SCALE
SHEET
Section View A-A
Scale: 1
M12X1.25mm pitch1.25
tide depth 30mm
Ø13
Ø19
35
Isometric View
Scale: 1/2
Left View Scale: 1
Section View B-B
Scale: 1
M12 X 2.5mm pitch 1.25
tide depth 30mm
2 X M12
46
96
120
25
70
45
Sliding fit with Pivot pin
Sliding fit with 3" pipe
Front View
Scale: 1
Top View
Scale: 1
Ø14
Ø10
Ø76.46
60
30
90
136
154
26
48
84
R10
R8


Φ17
Φ17
Φ17
549.91
288.91
40
1800
924.8
771.59
73.61
1800
30
Front View
Scale 1:1
Side View
Scale 1:1
100
86
45
50
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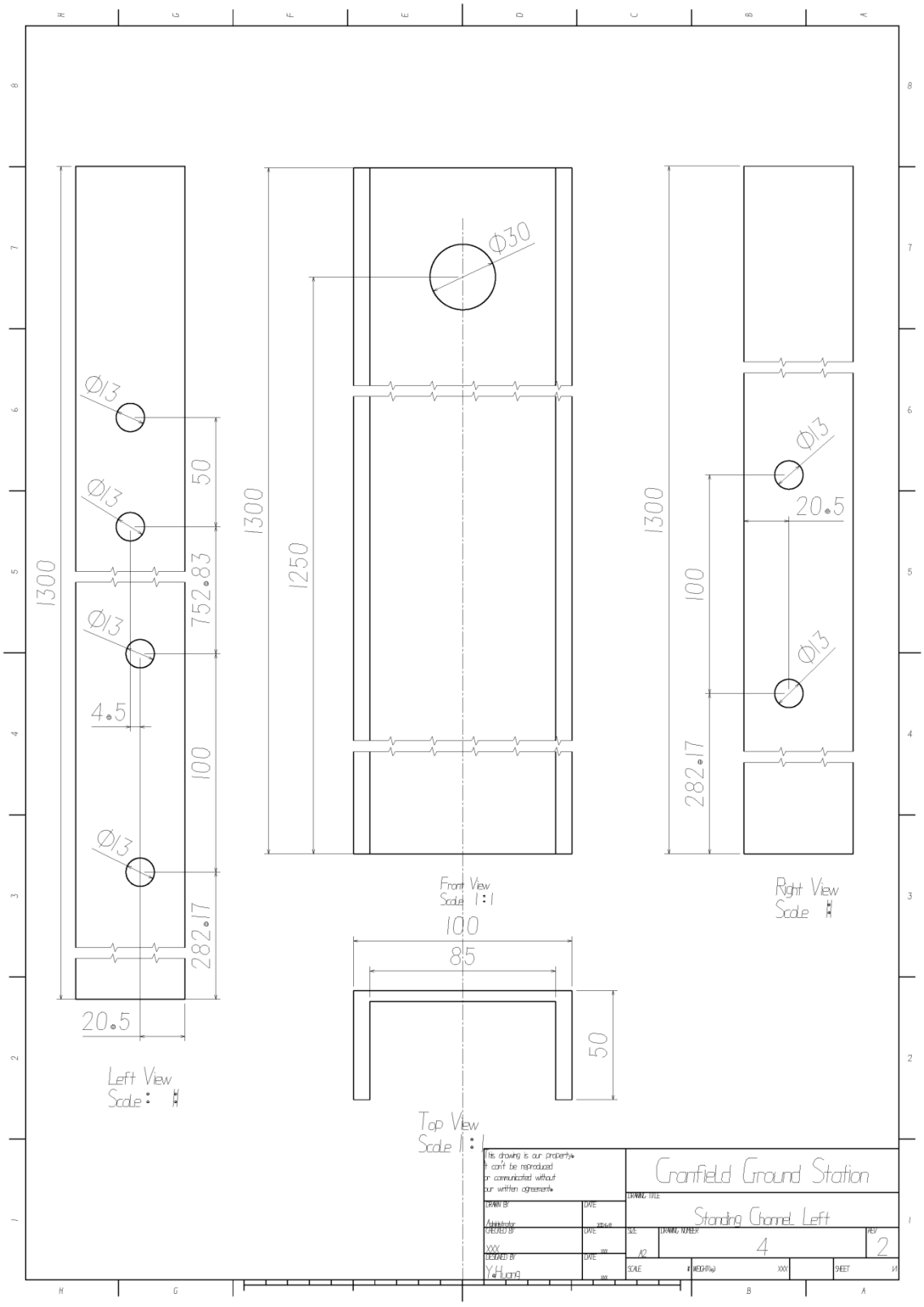
Cranfield Ground Station
DRAWING TITLE
Lying Channel
DRAWING NUMBER
5
REV
2
SIZE
A2
SCALE
SHEET
DRAWN BY
Administrator
CHECKED BY
XXX
DESIGNED BY
Y.H Liang
DATE


Ø30
Ø13
Ø13
Ø13
Ø13
Ø13
1300
50
752.83
4.5
100
282.17
20.5
1300
1250
1300
100
282.17
20.5
100
85
50
Left View
Scale : 1
Front View
Scale 1 : 1
Right View
Scale 1
Top View
Scale 1 : 1
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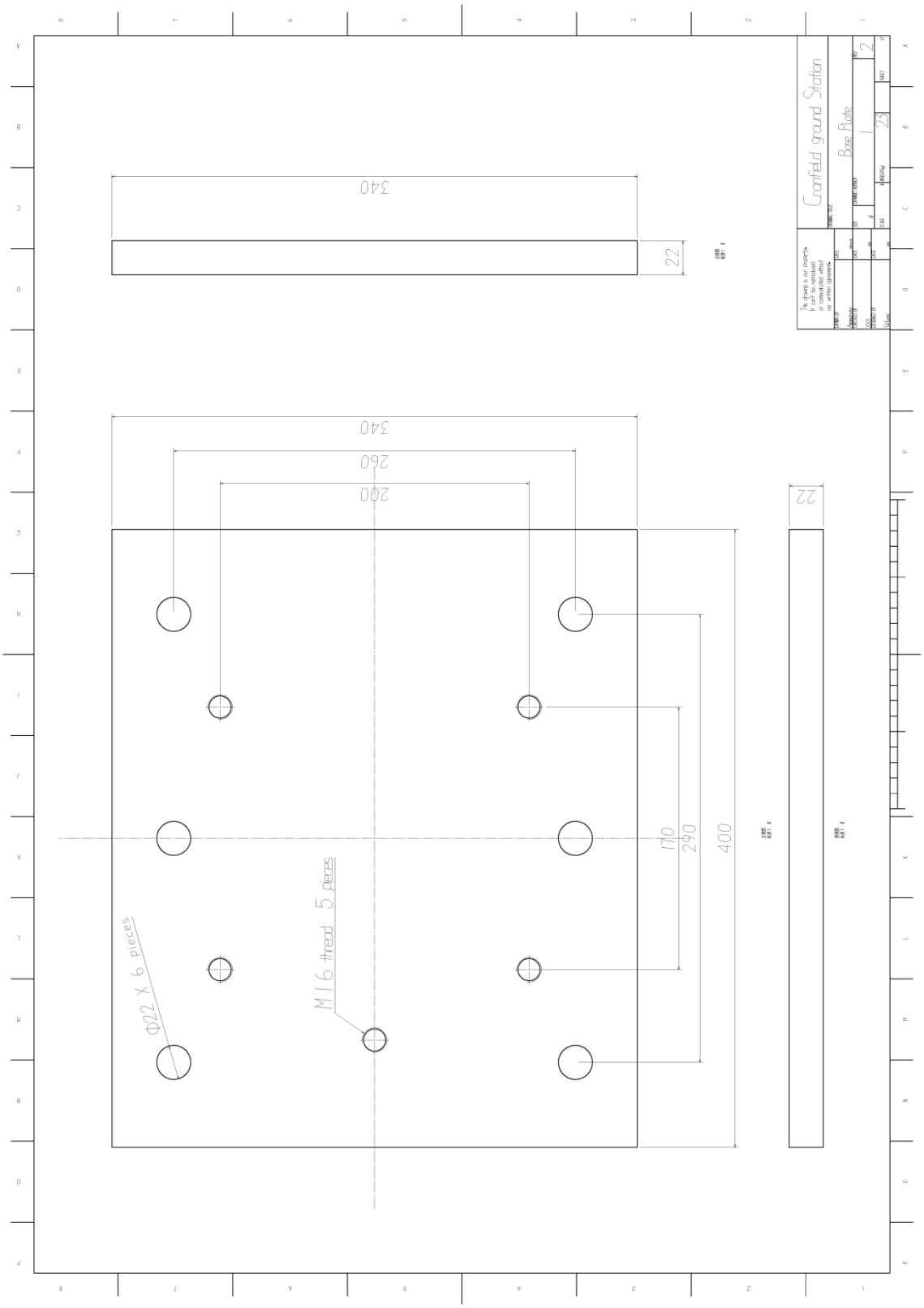
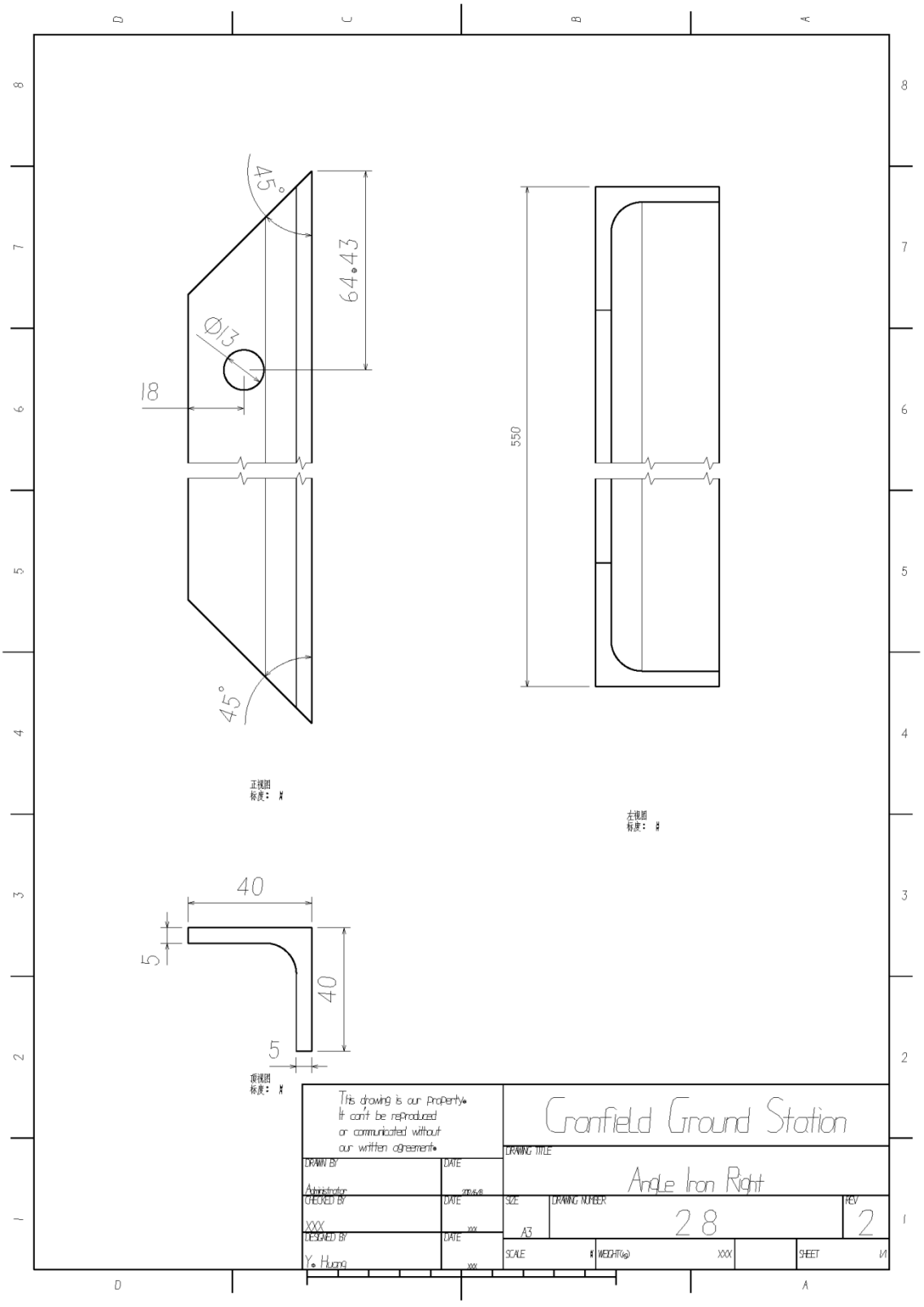
Cranfield Ground Station
DRAWN BY
Administrator
DATE
CHECKED BY
XXX
DESIGNED BY
Y.H Liang
DRAWING TITLE
Standing Channel Left
SIZE
A2
DRAWING NUMBER
4
REV
2
SCALE
WEIGHT(kg)
XXX
SHEET


Cranfield ground Station
Base Plate
340
22
340
260
200
22
170
290
400
M16 thread 5 pieces
Φ22 X 6 pieces


45°
64.43
Ø13
18
45°
正视图
标度：
550
左视图
标度：
40
5
40
5
顶视图
标度：
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Cranfield Ground Station
DRAWING TITLE
Angle Iron Right
DRAWN BY
Administrator
DATE
CHECKED BY
XXX
DATE
DESIGNED BY
Y. Huang
DATE
SIZE
A3
DRAWING NUMBER
28
REV
2
SCALE
WEIGHT(kg)
XXX
SHEET